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ESTIMATING POTENTIAL COST GROWTH
OF THE MOST PROBABLE COST ESTIMATE

THESIS

Pamela J. Singleton, Captain, USAF

AFIT/GCA/LSQ/91S-11

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THESIS

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Pamela J. Singleton, B.S.

Captain, USAF

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I dedicate this thesis to my daughter, Debora, whose infectious smile helped me keep my sanity and all things in perspective. Last, but not least, I thank God for being there always.

Pamela J. Singleton

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Abstract

The escalating costs of military weapon systems are constantly under scrutiny. In today's environment of reduced funding it is imperative that an effective method of assessing likely cost growth be available early in the acquisition life cycle, and especially during the source selection process. This research sought to identify a method for predicting the range of cost growth around the most probable cost estimate generated during the source selection process. With the assistance of the Research and Cost Division of Aeronautical Systems Division, three factors were determined to be major contributors to cost growth for ASD programs; technical risk, configuration stability, and schedule risk. The data base consisted of 16 programs from ASD from 1980 to 1988. The results of this research provides a method for quickly assessing the range of potential cost growth of the most probable cost estimate; however, due to the small data set, more research must be conducted to increase the method's usefulness. Although more research is required, based on the data set used, configuration stability appears to be a more significant driver of cost growth in the development phase. While, schedule risk appears to be more significant in the production phase.

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I. Introduction

General Issue

The escalating costs of military weapon systems have been under constant scrutiny since the late sixties. Much of this attention is focused on the increase in cost over the originally estimated program costs (22:1). In today's environment of reduced funding, and with the perception by the general public that the military does not manage or is incapable of managing its money prudently, it is imperative that a method of determining potential cost growth be available early in the acquisition life cycle. If such a method is not employed, the acquisition cost of weapon systems will continue to experience unanticipated cost growth. Cost growth reduces the DOD's ability to procure the number and type of weapons necessary to meet force structure requirements (27:1). The Navy's A-12 Aircraft Program is the most recent example of a program that initially suffered a reduction in quantity and was subsequently canceled.

The A-12 aircraft was being developed by the Navy as a replacement for the Navy A-6 Intruder aircraft, the Navy's primary all-weather, medium-attack aircraft (34:1). In December 1989, the Secretary of Defense (SECDEF) directed a Major Aircraft Review (MAR) of four major aircraft programs (34:2). The recommendation after the MAR was that the A-12 aircraft program be continued, but at reduced procurement quantities (34:2). On June 1, 1990, the contractor team developing the A-12 advised the Navy that there would be a slip in the schedule for the first flight and that the Engineering and Manufacturing Development (EMD) effort would overrun the contract ceiling by an amount that the contractor team could not absorb (34:2). In October of 1990 the concerns of the Chairman of the House Arms Services Committee, Les Aspin, led to a special review of the Navy's A-12 program (34:i). The review, conducted from October 1990 to January 1991, "disclosed that the cost, schedule, and technical problems in the A-12 aircraft program were of such magnitude that the continued viability of the program was in serious doubt" (34:i). On December 31, 1990, the contractor team submitted a certified Claim for Equitable Adjustment for the EMD contract (34:12). This claim proposed a $1.4 billion increase in the EMD target price (34:12). On January 7, 1991, the SECDEF decided to cancel the A-12 aircraft program for default (34:13). Though there were several factors leading to the cancellation of the A-12 aircraft program, it is apparent that the inability to control cost was a major player in the final decision.

Despite efforts to control cost growth, there continues to be unforseen increases in cost from the most probable cost estimate generated at source selection to the actual costs incurred by the government. Part of this problem can be linked to the manner in which cost is presented to the decision makers. In his report, "Risk and the Right Model," Lt Colonel John A. Long recommends providing decision makers with a range of -obable cost to ensure they have enough information to r e an informed dec-sion. The need for this additional information is summarized in the following statement by Long:

> Normally decision makers are presented with only a point or 'most likely' cost estimate, with no indication as to the risk (variability) in that estimate . . . But, point estimates can be misleading and can lead to a worse decision than had no estimate at all been used. (41:2)

Figure 1 provides a graphical representation of how not providing all the information can be misleading. In Case I, decision makers are faced with no real decision problem because all possible costs of System A are lower than System B. In Case II, there is the possibility that the actual cost of System A will be higher than System B. The overlap in Case II is not significant so System A is still preferable to System B; however, if the overlap were significant "the point estimate would no longer provide a valid datum for system selection" (41:3). In Case III, both point estimates are the same, but the cost for distribution B has a larger range or variance. Preference toward risk

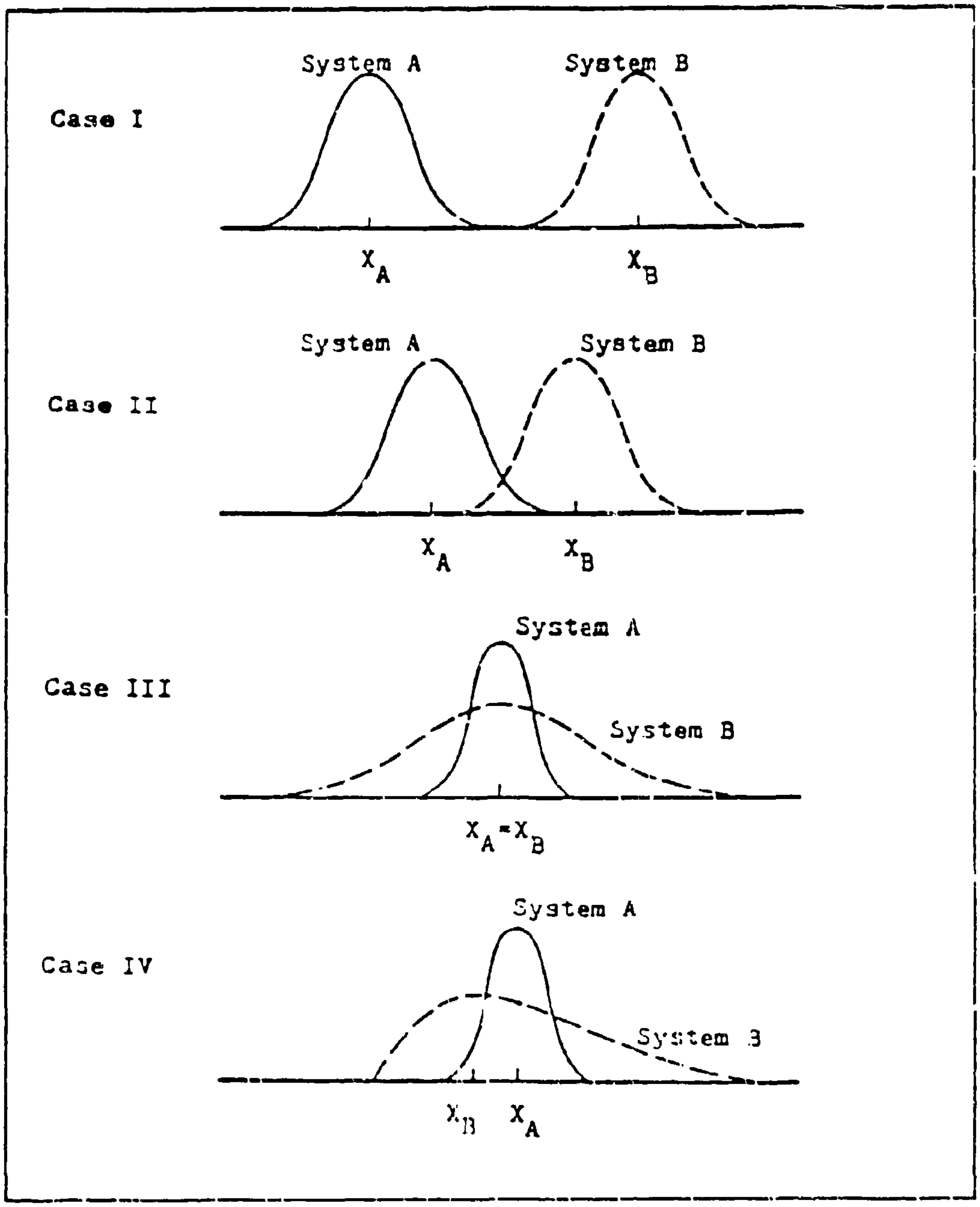

Figure 1. Impact of Cost Risk on Decision Making

must come into play in making the decision in this instance. Case IV presents yet another problem. The expected cost of System B is lower than System A, but has more uncertainty. The point estimate alone would not provide insight into the potential cost growth of System B.

According to Long, the problem with presenting data in the manner indicated above is that many decision makers are only interested in a point estimate (25:42). He cites four predominate reasons for this:

> First, presenting more than a point estimate may constitute information overload. Cost is but one input to the decision process. Information presented must be clear, concise, and easily understood. Secondly, some decision makers would not understand risk analysis and its associated implications. Third, the possibility of high costs would cause undue concern and adversely affect the decision. Fourth, risk analysis would impact the credibility of the study giving the impression that analysts were unwilling to stand behind their analyses. (41:3)

Long notes that though decision makers did not want the range of expected risk, they did feel the cost analysts should conduct such analyses for their own benefit and in support of the point estimate (41:4). The commander of the Aeronautical Systems Division of Air Force Systems Command, General Ferguson, also expressed the need to provide decision makers with a range of potential cost growth around the most probable cost (MPC) of each bidding contractor (38).

Specific Problem

During the source selection process a team of government cost analysts, often called the cost panel or cost-to-government team, develops a most probable cost (MPC) estimate for each contractor bidding to develop and/or produce the system or program. The purpose of the MPC is to protect the government's interest by insuring a contractor does not "buy into" the contract by submitting an unrealistically low bid (20:15-21). If a range of potential cost growth is not provided around the MPC point estimate decision makers will not have all the information necessary to make the best decision. Currently, an acceptable method of determining such cost growth is not available to be utilized early in the acquisition life cycle (38).

There needs to be a method of determining the range of potential cost growth early in the acquisition of weapon systems. Due to the uncertainties inherent early in the acquisition life cycle and the time constraints in the source selection environment, this method must make use of information available early in a system's life and be simple enough to use in the limited time available.

Scope and Limitations

This research will concentrate on developing a method to improve the usability of the most probable cost generated during the source selection process. Though cost growth is experienced in all phases of weapon system acquisitions, the focus of this research is on cost growth from the development and production most probable cost estimates to the current estimate. The data base consists of major and non-major weapon systems that were initiated in the past decade, 1980 - 1988, at Aeronautical Systems Division. A major system is defined by DoDI 5000.2 as:

> A combination of elements that will function together to produce the capabilities required to fulfill a mission need, . . . A system shall be considered a major system if it is estimated by the Under Secretary of Defense to require:
>
> a. An eventual total expenditure for research, development, test and evaluation of more than $75,000 in fiscal year 1980 constant dollars ($115,000,000 in fiscal year 1990 constant dollars), or
>
> b. An eventual total expenditure for procurement of more than $300,000 in fiscal year 1980 constant dollars ($540,000,000 in fiscal year 1990 constant dollars). (33:3)

There are a number of factors and events inherent in the development, production and fielding of a weapon system. An attempt to capture all of these factors is beyond the scope of this research. The data set is limited to those programs initiated at Aeronautical Systems Division and may not be applicable across commands.

Research Objective

The objective of this research is to develop a method for predicting a realistic range of potential cost growth around the Government's most probable cost estimate.

Investigative Questions

The following investigative questions will be asked:

1. What are the major sources of cost growth in the development of weapon systems?

2. How can these sources of major cost growth be used to help predict potential cost growth of weapon systems.

3. How can this information be used to estimate a range of potential cost growth around the most probable cost estimate developed during the source selection process?

Summary

Cost growth continues to be a problem in weapon systems acquisition. Providing a range of probable cost growth around the most probable cost estimate (MPC) would greatly enhance the value of the MPC to decision makers.

In the following chapters, cost growth and the reasons for cost growth will be explored. Chapter II consists of a review of the literature concerning the system acquisition process, the source selection process, estimating techniques, and cost growth in weapon system acquisitions. Chapter III highlights the methodology used for data collection and developing the method for predicting a range of cost around the MPC. In Chapter IV, findings and analysis of data collected in Chapter III are discussed, followed by conclusions and recommendations for further research in Chapter V.

II. Literature Review

Chapter Overview

Cost growth is not uncommon in the acquisition of weapons systems and is often addressed in the literature. Nonetheless, there is still confusion over what causes cost growth and whether or not it can be controlled. This chapter begins with a discussion of the acquisition and source selection processes and the role of cost estimating in these processes. Followed by a discussion on cost growth, its causes, trends, and some initiatives aimed at curtailing the problem.

The literature search was conducted using Dissertation Abstracts; on-line search capabilities at the Air Force Institute of Technology, University of Dayton, and Wright State University libraries; a Defense Technical Information Center (DTIC) search of cost growth covering the last twenty years; and research at the Aeronautical Systems Division Cost and Publications Libraries.

The Systems Acquisition Process

According to Department of Defense Instruction (DoDI) 5000.2, Defense Acquisition Management Policies and Procedures, an acquisition program is "a directed, funded effort that is designed to provide a new or improved materiel capability in response to a validated need" (33:2).

The system acquisition process is the process by which these programs are acquired. There are five major decision points and five distinct though sometimes overlapping, phases that provide the basis for "comprehensive management and the progressive decisionmaking associated with program maturation" (33:11). The Milestones are Milestone 0, Concept Studies Approval; Milestone I, Concept Demonstration Approval; Milestone II, Development Approval; Milestone III, Production Approval; and Milestone IV, Major Modification Approval. The phases are Concept Exploration and Definition, Demonstration and Validation, Engineering and Manufacturing Development (EMD), Production and Deployment, and Operations and Support (O&S).

A primary goal in developing an acquisition strategy is to minimize the time it takes to satisfy an identified need consistent with common sense, sound business practice, and the provisions of DoD Directive 5000.1 and DoDI 5000.2 (33:16). With this goal in mind, DoDI 5000.2 makes provisions for tailoring the acquisition process to fit the needs of the specific program or system being acquired (33:16). Tailoring must be based on an objective assessment of the program's status and risk and cannot eliminate core activities which must be accomplished for every acquisition program (33:16).

> These core activities establish and document the threat and operational requirements affordability, the acquisition strategy and program baseline, cost and operational effectiveness, production

readiness and supportability and developmental and operational testing. (33:16)

In the following paragraphs the criteria used to determine decision authority of the five milestones and the five phases of the acquisition process are discussed.

Acquisition Milestones The five milestones represent the points where the decisions are made on the future of a program. The level at which these decisions are made depends on the classification of the program. All acquisition programs, with the exception of highly sensitive classified programs, are placed into one of four categories (33:12).

Milestone Decision Authority. Acquisition Category I programs, are major system acquisitions that have "statutorily imposed acquisition strategy, execution, and reporting requirements" (33:12). Programs in Acquisition Category I are estimated to have an eventual expenditure for research, development, test and evaluation of more than $200 million in fiscal year 1980 dollars or more than $1 billion in fiscal year 1980 dollars for procurement (33:13). The Under Secretary further designates Acquisition Category I programs as Acquisition Category ID, requiring decisions by the Under Secretary, or Acquisition Category IC, requiring decisions by the cognizant DoD Component Head (33:13). Acquisition Category II programs are major systems that do not meet the criteria for Category I, but have unique statutorily imposed requirements in the test and evaluation area (33:13). They may also have unique statutorily imposed requirements in other areas such as Defense Enterprise Programs and multiyear procurement. The milestone decision authority for Acquisition Category II cannot be delegated lower than the DoD Component Acquisition Executive (33:14). Acquisition Category III programs are those not meeting the criteria for Category I and II, that have been designated Category III by the DoD Component Acquisition Executive (33:13). The decision for Category III programs may be delegated by the DoD Component Acquisition Executives to the lowest level deemed appropriate within their respective organizations (33:13). Category IV programs are all other programs, non-major, which may be delegated by the DoD Component Acquisition Executive to the lowest appropriate level (33:13).

Milestones 0, Concept Studies Approval. At this milestone the decision authorities analyze the Mission Need Statement (MNS) to determine if the need identified warrants the initiation of study efforts of alternative concepts to satisfy the need (33:27). Based on this analysis, they decide whether or not to move into the Concept Exploration and Definition Phase (33:24).

Milestones I, Concept Demonstration Approval. At this decision milestone, decision authorities assess the affordability of a new acquisition program (33:31). A favorable decision establishes a new program and a Concept Baseline; initial program cost, schedule, and performance objectives, and authorizes entry into Phase I (33:31).

Milestone II, Development Approval. At this milestone, decision authorities meet to determine if the results of Phase I, Demonstration and Validation, warrant continuation into the next phase.

Milestone III, Production Approval. A favorable decision at this phase represents a commitment to build, deploy, and support the system (33:44). Decision authorities must determine if the results of the Engineering and Manufacturing Phase, the phase preceding Milestone III, warrant continuation of the program and establish a Production Baseline. This baseline contains refined program cost, schedule, and performance objectives of the given program.

Milestone IV, Major Modification Approval. This milestone is conducted as required. A major modification is defined as a program that meets the criteria of Acquisition Category I or II or is designated as such by the decision authority (33:49). The intent of this milestone is:

> To ensure that all reasonable alternatives are thoroughly examined prior to committing to a major modification or upgrade program for a system that is still being produced (33:49).

Phases of the Acquisition Process. The milestones, discussed above, link the phases of the acquisition process. Though these phases are distinct, there may be some overlap between phases.

Phase 0, Concept Exploration and Definition. The objectives of this phase are to: (1) explore various alternatives that can satisfy the documented mission need (this need is normally defined by the operational command, but can be defined by other sources such as contractors, military groups, and research organizations such as The RAND Corporation and The MITRE Corporation) (39:11); (2) define the most promising concept(s); (3) Develop analyses and information identifying high risk areas and risk management approaches to support the Milestone I decision; and (4) develop a proposed acquisition strategy and initial program objectives for cost, schedule, and performance for the most promising system concept(s) (33:29). This phase provides the basis for assessing the relative merits of the concepts at Milestone I (33:28).

Phase I, Demonstration and Validation. The objectives of this phase are to: (1) better define the critical design ch racteristics and expected capabilities of the system concept or concepts identified in the previous phase; (2) demonstrate that the technologies can be incorporated into the system design with some degree of confidence; (3) develop analyses that are needed in order to make the Milestone II decision; (4) assessing whether the most promising concept designs will operate in the intended operational environment and proving that these designs are understood and attainable; and (5) establish a proposed development baseline containing refined program cost, schedule and performance objectives (33:35). Much of the design analysis in this phase is accomplished by the contractor or contractors who desire to be awarded the development and production contracts (37:5). In cases where there are two or more contractors, each contractor performs independent analysis and design studies and arrives at a design proposal, which is then evaluated in the source-selection process. The source selection process will be explained later in this chapter.

Phase II, Engineering and Manufacturing Development. The objectives of this phase are to: (1) translate the most promising design approach developed during the Demonstration and Validation Phase into a stable, producible and cost effective system--this design should be refined in terms of financial and technical risk associated with long-term production (37:7); (2) validate the manufacturing or production process; and (3) demonstrate the system capabilities by testing to determine if the system meets contract specification and performance requirements, and to ascertain whether the system satisfies the mission need (33:43).

Phase III, Production and Deployment. The objectives of this phase are to (1) establish a stable and efficient production and support base; (2) achieve an operational capability that satisfies the mission need, and (3) conduct follow-on operation and production verification testing to confirm and monitor performance and quality of the system (33:48). Support plans will be implemented in this phase to ensure support resources are acquired and deployed with the system.

Phase IV, Operations and Support. Though operation and support (O&S) have long been a part of the acquisition life cycle, it has only recently been singled out as its own phase. This was done to emphasize the importance of operations and support in the planning phase. The O&S phase begins after the initial systems have been fielded and overlaps the production and deployment phase (33:51). The beginning of this phase is marked by either the declaration of an operational capability or the transition of management responsibility from the developer to the maintainer (33:51). The primary objectives of this phase are to (1) ensure the fielded system continues to provide the capabilities required to meet the identified mission need and (2) identify shortcomings or deficiencies that must be corrected to improve performance (33:51).

<u>The Role of Cost in the Systems Acquisition Process</u>. One underlying theme prevails throughout the acquisition process; this theme is <u>cost</u>. What are the costs associated with this system and are the resources available to support the system?

In the early days of a program's life cycle a great deal of information crucial to the future of the program is sought by the decision makers (20:1-9). Precise cost estimates are sought, but programs may not have been defined well enough to make precision possible (20:1-9). Decisions made early in the acquisition life cycle of a program have great influence over the program's content, configuration, and cost. Unfortunately, ther is little information early in the program that can assist in making these important program decisions. The situation cost analysts and decision makers are faced with is depicted in Figure 3, taken from The AFSC Cost Estimating Handbook. As time passes, more information is known about the system and cost estimates are likely to be more accurate, but the estimates made during periods of certainty have less impact on program configuration and content, and subsequently, less impact on cost.

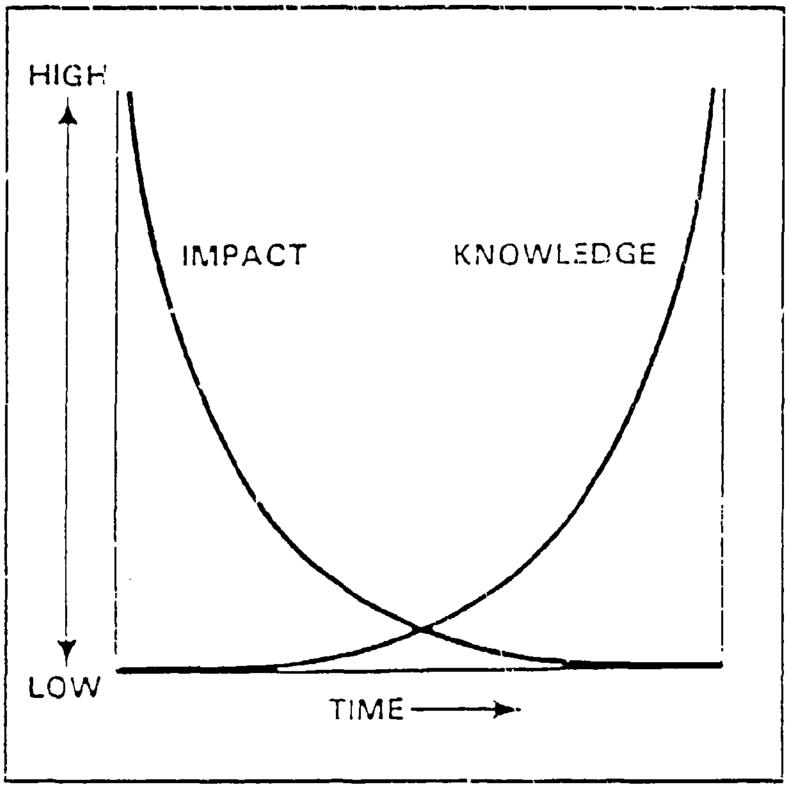

Figure 2. Milestone I Dilemma

Planning Estimate. Cost information is required in the system acquisition process as early as the Concept Exploration and Definition Phase. During this phase one of the objectives is to develop the initial program objective for cost. This estimate, developed by government cost analysts, is known as the planning estimate. The planning estimate is conducted very early in the conceptual phase of the acquisition process (22:8) and is the baseline estimate for technical and operational characteristics, schedule milestones and program acquisition cost (32:2-2).

Most Probable Cost and Development Estimate. During the Demonstration and Validation Phase two cost estimates are of importance; the most probable cost (MPC) estimate and the development estimate (DE). "The MPC represents the Government's estimate for each competing bidder in the source selection environment" (20:2-15) and should capture any peculiarities associated with each offeror's proposal (20:15-23). The MPC is conducted by a team of cost analysts known as the Cost-to-Government Team or the Cost Panel. The basic consideration of the MPC estimate is "determining if the offeror's proposed costs are commensurate with the technical effort proposed..." (2:52). This estimate is used by the Source-Selection Authority to assist in choosing the winning contractor and often becomes the only meaningful measure of the realism of the contractor's cost proposal (20:2-15). The development estimate (DE), is the baseline "estimate of technical and operational characteristics, schedule milestones, program acquisition cost (by appropriation), and annual production rates" (34:2-1) The DE is prepared toward the end of the Demonstration and Validation Phase, and usually approximates the target price of the contract (22:8). This estimate normally serves as the baseline to which all program changes are compared (43:6).

Current Estimate. The current estimate is the DoD Component's latest forecast of the system's final costs, technical and operational characteristics, schedule milestones, and annual production rates (32:2-1). This estimate is continually updated throughout the life of the program (43:6).

Though there are only four estimates mentioned above, many other cost estimates are conducted, updated and revised throughout the weapon system acquisition process. The list includes such estimates as the should cost estimate (SCE), the independent cost analysis (ICA), and the program cost estimate (PCE) (20:2-14,2-15).

Cost Estimating and the Source Selection Process

One of the primary objectives of the source selection process is to:

> Select the source whose proposal has the highest degree of realism and credibility and whose performance can be expected to best meet the government's requirements of an affordable cost (31:3).

In the following paragraphs the role of cost estimates during the source selection process is highlighted.

The Source Selection Process. The AFSC Cost Estimating Handbook defines four phases of the source selection process:

(1) Pre-evaluation phase

(2) Initial evaluation phase

(3) Intermediate evaluation phase

(4) Final evaluation phase

These phases will be defined below with a discussion of the role of the cost estimates in each phase.

<u>Pre-evaluation Phase</u>. This phase typically begins with the submission of a Justification for Major Systems New Start, which leads to the issuance of one or more Program Management Directives (PMD) (20:15-3). Upon release of the PMD the chairperson of the Source Selection Advisory Committee notifies all appropriate Air Force Commands and potential offerors that source selection action is in progress (31:13). The Source selection Plan (SSP) and the solicitation are two of the most important documents prepared during this phase (20:15-4).

<u>Source Selection Plan (SSP)</u>. The SSP is the plan for organizing and conducting the evaluation, the analysis of proposals, and the selection of the source or sources to satisfy the system requirements (36:15-4). The contents of this document are outlined below (20:15-4):

(1) Source selection organization

(2) Screening criteria to determine sources to receive solicitations

(3) Evaluation criteria

(4) Acquisition strategy

(5) Schedule of events

(6) Evaluation procedures to be used to evaluate proposals

The section on evaluation procedures is important to the cost analyst and should include inputs from cost analysts in its development. This section includes procedures and plans for formulating the MPC to the government; developing the independent cost analyses, life cycle cost estimates, and design-cost-goals; identifying items requiring special attention and non-quantifiable cost risks; and evaluating offerors proposals (31:12).

Solicitation. The solicitation is the final step in the pre-evaluation phase (20:15-5). The solicitation for bid is commonly referred to as the Request for Proposal (RFP) (20:15-5). The RFP contains a comprehensive description of the work to be performed, instructions on how to prepare proposals, evaluation criteria, and the basis for award (20:15-5). Phase II, Initial Evaluation begins with receipt of the proposals (20:15-7).

Initial Evaluation Phase. During the Initial Evaluation Phase the cost analyst first reviews the proposals to ensure all the cost data formats required by the RFP have been submitted. If all the required formats are not provided, the contractor is given the opportunity to submit the requested data. Once this is complete, the next step is the initial evaluation itself.

Initial evaluation of each proposal is reviewed against criteria set forward in the SSP. The proposal is checked for reasonableness, realism, and completeness. Reasonableness is used to evaluate the acceptability of the bidder's methodology (2:52). Realism is used to evaluate the compatibility of costs with the scope of the proposal, ensuring that the estimate is neither excessive nor insufficient for the effort to be accomplished (20:15:19). The estimate also must be consistent with the requirements of the Request for Proposal (RFP), Statement of Work (SOW), and ". . . all information required by these, including appropriate program ground rules, schedules, and constraints. . ." (2:53). Completeness is used to evaluate the "responsiveness of the offeror in providing all RFP requirements, statement-of-work (SOW) items, and traceability of the estimates" (20:15-20).

The initial MPC estimates are conducted parallel with the reasonableness, realism and completeness evaluations. This estimate is refined and updated as more information becomes available and does not become final until the Best and Final Offer (BAFO) is received and evaluated (20:15-8).

One of the primary goals of the initial evaluation phase is to prepare for discussions with the offerors (20:15-9). The initial evaluation phase is followed by the Intermediate phase (20:15-9).

Intermediate Phase. The primary task of the cost panel in the intermediate phase is supporting discussions with offerors and adjusting the initial MPC estimates and evaluations as the offeror's intentions become more clearly defined (20:15-9). The purpose of the contractor discussions is for each side, both the government and contractors, to become more knowledge about the other's intentions and clarify outstanding issues (20:15-9). At the end of this phase the offerors' designs are usually firm and the MPC is completed based on this stabilized design (20:15-9).

Final Phase. During the final phase, the MPC estimates and evaluations have to be finalized (20:15-10). The evaluations are presented to the Source Selection Advisory Council (SSAC), who then rates the proposals and presents their findings to the Source Selection Authority (SSA). The SSA then makes the source selection decision, and the contracting officer awards the contract(s) to the winner(s) (20:15:14).

Estimating Techniques

The cost estimating tasks explained during the acquisition and source selection processes are accomplished using various techniques available to the cost analyst. Four of these techniques are explained in the following paragraphs.

Parametric Approach. Parametric estimating is accomplished by correlating design parameters to historical costs with the use of regression analysis. It often uses cost estimating relationships (CERs) to help predict future weapon systems costs (40:3). CERs relate costs as the dependent variable to one or more independent variables. The parametric technique is used most often when there is limited program and technical definition (20:3-21).

Analogy Approach. The "analogous" or "comparative" method is derived by choosing analogous programs that have previously been completed and for which cost data is available (39:26). The cost analyst derives estimates for the new program by adjusting for complexity, technical, or physical differences. This method is normally chosen early in the cycle when there is insufficient actual cost data to use as a basis for a detailed approach; but there is a sufficient amount of program and technical definition based on study results and test data (20:3-24).

The Grass Roots Approach. The grass roots method, also referred to as the "detailed" or "engineering" estimate, involves breaking down the project into detailed work segments that can be individually estimated at an assumed high level of accuracy. The grass roots estimate would normally be utilized during the production phase of the program cycle when program configuration has stabilized (20:3-25).

Expert Opinion Cost Estimates. This is a subjective technique that is difficult to analyze and substantiate (39:31). This method is best applied on new products that are beyond the current state of the art (39:31).

The estimating techniques above are not necessarily used exclusively. In any given program one two, three or all four of the techniques will be used in estimating the cost of the program. The estimator chooses and combines estimating methodologies based on the estimating task to be accomplished (20:3-28).

Cost Growth

The AFSC Cost Estimating Handbook defines cost growth as, "A term related to the net change of an estimated or actual amount over a base cost figure previously established" (20:A-22). In his paper, "Cost Growth and the Use of Competitive Acquisition Strategies," Frederick Biery defines cost growth as, "The difference between the actual costs (or the most current estimate of actual costs) and the estimate at the start of the system's development" (23:1). In the Congressional Budget Office's report, "Cost Growth in Weapon Systems: Recent Experience and Possible Remedies," cost growth refers to the tendency for the unit cost of a system to increase during the course of the acquisition process (33:2). In his doctoral dissertation, Major Richard Sapp states that because the term cost growth is not standardized it has led to "misunderstandings and communication difficulties, as well as making comparisons of available research work and studies difficult" (46:15). He notes that the term is often used interchangeably with the terms contract growth, cost estimate growth, program cost growth, price increase, etc., but was originally intended to refer to increases in costs due to influences beyond the control of the weapon system acquisition program managers (46:15). Cost growth, in the context of this research, is consistent with Biery's use of the term, the difference between the actual cost (or the most current estimate of actual costs) and the estimate made at the start of the system's development. The term "actual cost" and "most current estimate of actual costs" will be used interchangeably.

Despite the different uses of the term cost growth presented in the literature, the consensus is that cost growth is inevitable. Though cost growth is widely accepted as unavoidable due to uncertainty in predicting the future, cost estimates are expected to reasonably predict the future and cost growth is expected to be kept under control. In order to control or solve a problem; first, the causes of the problem must be identified and secondly, measures aimed at eliminating or reducing these causes must be implemented.

Unanticipated cost growth in weapon system acquisitions, is complicated by a myriad of sources identified as contributors to the problem. In the following section some of the contributors to cost growth identified in the literature will be discussed.

Reasons for Cost Growth. A 1982 House Arms Services Committee Special Panel on Defense Procurement Procedures identified poor cost estimates, program stretch-outs, changes in weapon systems specifications, inadequate budgeting, unrealistic inflation estimates, and lack of competition as controllable factors (as opposed to uncontrollable factors such as inflation) that cause cost growth (27:2). In his article, "Military Systems Procurement," John Adam attributes cost growth to unrealistic performance and cost schedules deliberately provided by contractors and accepted by program management in order to get program contracts (1:30). A 1979 Rand Corporation report, conducted by Edmund Dews, et al., identified schedule slippage, engineering changes, estimating errors, and changes in the support area as the major sources of cost growth in the 1970s (35:91). The major reason given for schedule slippa in this Rand report was inadequate funding levels, while the engineering variances were attributed to unexpected technical difficulties and changes in the performance requirements of the system (35:92-93). The estimation errors were found to be the result of mistakes in estimator judgement such as inappropriate analogies or estimating relationships and omission of costly system elements such as training or depot equipment (35:93). Yet another approach to analyzing cost growth was taken by Major Martin D. Martin. In his doctoral dissertation, Martin separated the causes for cost growth into two categories; pre-activation and activation.

> Pre-activation refers to the time period between technical and cost proposal preparation and the time that the contract is signed by both parties. Activation refers to the contract administration and closure. (28:87)

In the pre-activation area, Martin includes such items as lack of competition, contractor underpricing, variability in past cost data, concurrency of research and development with production, extraneous design requirements, faulty technical planning, inadequate task definition, reliability problems, budgetary constraints, and communication problems. In the activation period he included such items as inflation, quantity variances, lack of cost control, inadequate management controls, program stretch-outs, engineering changes, and technological obsolescence (42:39). By observing cost growth in two separate phases Major Martin emphasized the need to understand not only why cost growth occurs, but also where it occurs.

The Congressional Budget Office (CBO) determined that the bulk of cost growth is likely to occur after the system enters the Engineering and Management Development (EMD) phase and before its full-scale production (47:3). In a study conducted by the Institute for Defense Analysis (IDA) it was shown that "achievement of Initial Operational Capability (IOC) marks the end of significant growth in both development and procurement costs for most systems" (21:28).

Measures to Reduce Cost Growth. Cost growth is not a problem unique to the DoD. In the General Accounting Office's (GAO's) tabulation of cost growth in major acquisitions of NASA, the DoD, and Federal non-defense agencies (those costing more than $50 million), they found that the average cost growth was 82 percent. The cost growth for defense alone for the same period was 79 percent, thus indicating that the defense cost growth is below average (26:10). Though other studies have also shown that cost growth experienced by the DoD is less than those experienced in the public sector (23:6), cost growth of weapon system acquisitions continues to be of concern to Congress, key decision makers, and the general public who would rather see funds spent elsewhere (37:69). It would be easy to point to findings such as the GAO's report mentioned above to try to negate the charges of individuals who criticize DoD's poor cost performance history. As Donald Chamberlain phrases it in his article to the 1985 National Estimating Society Conference, "Using Labor Standards for Estimating":

> We can search to find fault with the accusers and attempt to discredit their allegations, or we can be more positive and spend our time searching internally for positive improvement techniques. (25:1)

The DoD has chosen the later approach and over the years has devoted a great deal of time and energy "searching internally for positive improvement techniques" to curtail cost growth.

Congressional dissatisfaction with cost overruns and late deliveries has given rise to a series of laws designed to improve the acquisition process and to identify problems which may result in cost growth or cost overruns as soon as possible (23:1). The initiatives of David Packard, Secretary of Defense form 1969 to 1971, had perhaps greatest impact on acquisition policy (35:1). Packard's initiatives emphasized ten major policy elements including the following cost considerations:

> 1. Design-to-cost: establish a cost goal as one of the primary program objectives, equal to schedule and performance in importance; design with operation and support costs in mind as well as production cost (life cycle costing). (35:2)
>
> 2. Improve program cost estimates and provide OSD [Office of the Secretary of Defense] with an independent source of such estimates by establishing a Cost Analysis Improvement Group (CAIG) within OSD. (35:2)

Some of the other initiatives were establishment of high level reviews for major weapon systems at important program decision points, better training and longer tours for program managers, and reduction in development and production concurrency allowing for increased testing during the development cycle (23:15). Packard also noted the high level of uncertainty in development programs and in 1969 it became mandatory to include risk analysis as part of the acquisition process (24:1).

Currently Air Force Systems Command Regulation (AFSCR) 173-2, requires that all cost estimates prepared, briefed and documented within Air Force Systems Command (AFSC) convey the basis of confidence using a qualitative method. AFSCR 173-2, specifies that the qualitative method provide an assessment of the availability and quality of data used in preparing the cost estimate (30:2). It assigns the estimate to one of the five following categories of confidence (30:2):

> Category I: Actual cost for significant production quantities is available for system being estimated.
>
> Category II: Actual cost for development or early production hardware is available for system being estimated.
>
> Category III: No actuals available, but system is well defined with good data for analogous, factor, parametric estimate or contract proposal.
>
> Category IV: No actuals available. System description is fair to good. Some data available for analogies, factors, parametrics, etc.
>
> Category V: Uncertain system description. Data available for analogies, factors parametrics, etc. are sparse or have limited value to system being estimated.

Once classified; however, AFSCR 173-2 does not further explain how these classifications can be used to determine the quality of the estimate. Whereas, most people would agree that more confidence should be pla ed in an estimate developed in Category I than one deve ed in Category V, this method does nothing to help the decision maker or cost analyst determine how much confidence should be placed in these estimates.

In addition, to the qualitative method of assigning confidence mentioned above, AFSCR 173-2 requires a quantitative method of risk assessment be accomplished when applicable. AFSCR 173-2 specifies that the AFSC Risk Model be used to accomplish the quantitative estimate (30:2). The AFSC Risk model is currently undergoing redesign to improve deficiencies noted in The Analytical Sciences Corporation's (TASC's) definition study of the Risk model. Surveys conducted by TASC during the definition study revealed that users felt the model was not user friendly and was too slow (36:3-4). Though the risk model was designed to be used at all phases in the acquisition life cycle (36:Appendix A), it is too cumbersome and time consuming to be used during development of the most probable cost during the source selection process (23). TASC's overall assessment of the AFSC Risk Model was that it is useful, but in need of improvements in order to gain user acceptance (36:7-1).

Trends in Cost Growth. The literature reviewed indicates a positive trend in cost growth from the 1950s to the early 1980s (23) (35) (47) (49). In his analysis of cost trends over three decades, Biery noted three factors whose influence might distort cost growth comparisons across the decades; improved documentation of original cost estimates, different make-up of the systems being used in each time period, and the length of time to field a system from initial estimate (23:9-13). Due to increased emphasis on cost estimating, the documentation of cost estimates improved in the 1970s over the 1950s and the 1960s; thereby, improving the ability to track cost growth (23:9). The difference in the make-up of the systems being procured could have an impact on cost growth if the propensity for cost growth depends on the type system being procured. In the 1950s aircraft systems made up the majority of the systems being acquired (23:9). In the 1960s aircraft only made up one third of the acquisitions and electronics made up half the programs (23:9). The 1970s sample is dominated by missile and gun systems followed by aircraft and cruise missiles (23:10). Further complicating the scenario, the Affordable Acquisition Approach Study noted an increase in the development and pre-development times in the acquisition of most weapon systems (29:2-54).

To account for theses distortions, Biery made comparisons between the decades using a compound annual growth rate and comparisons of means (average cost growth) (23:11). However, to ensure the comparisons were equitable, Biery used the following formula to normalize for the increased development effort:

$$CF = (1+R)^T \tag{1}$$

where

CF = actual cost/estimated cost
R = the rate of growth
T = the time from start of FSD

The results of Biery's analysis contained in the tables below suggests that there have been improvements in the accuracy of weapon system cost estimates over the years. Though he shows improvement over the years normalizing for the length of the program, the lengthening of the development cycle has eroded the effects of these improvements in real terms (23:12).

The same downward trend was observed when Biery observed the dispersion or "spread" around the means for each decade. The dispersion around the mean is measured by the standard deviation and the dispersion around the growth rate by the standard error of the estimate.

Table 1

Cost Growth Decade Comparison (23:12)

Decade	Average Program Age (Years)	Mean	Compound Annual Growth Rate %
Early 1950s	3.81	1.36	14.0
Early 1960s	[illegible].60	1.45	7.3
Early 1970s	[illegible].22	1.59	[illegible].0

Table 2

Cost Factor Dispersion By Decade (23:13)

Decade	Mean	Standard Deviation	Compound Annual Growth Rate %	Standard Error of the Estimate
1950s	1.86	1.386	14.0	0.028
1960s	1.45	0.441	7.8	0.023
1970s	1.59	0.481	5.0	0.007

The results of Biery's analysis show that there has been improvement in military cost forecasting accuracy since the 1950s (23:3). The records have not gotten any better in actual dollar amount of overruns because of the lengthier forecasting horizons (23:14).

A 1979 Rand Corporation study, Acquisition Policy Effectiveness: Department of Defense Experience in the 1970s, showed the same reduction in real cost growth from the 1960s to the 1970s. The real cost growth for major weapon systems averaged 7 to 8 percent annually during the 1960s, compared with 5 to 6 percent annually for major weapon systems in the 1970s (35:56). A study by the Defense Sciences Board also showed a decrease in the cost growth rate from the 1960s to the 1970s (12:68). Though the downward trend experienced in the 1970s may suggest that the cost growth problem is under control, a 1983 report by the Congressional Budget Office (CBO), suggests that the cost growth trend seems to be increasing in the 1980s (47:2). In the Institute for Defense Analysis document, Issues in

Measuring Cost Growth, Tyson, et al., noted that many policy makers in the early 1980s speculated that cost growth was a thing of the past (48:12). Tyson, et al., highlighted several factors which could have distorted cost growth experienced in the early 1980s:

> New Programs. During the 1980s, there was an unusually large number of new starts. In the 1981-85 period alone, at least 18 major programs went into FSD. As shown in a number of studies, cost growth is relatively low in new programs, and tends to increase as uncertainty decreases and reality is faced. (48:13)
>
> Program Funding. Programs in the 1980s were amply funded, due to the defense buildup. Therefore. cost analysts have less incentive to be optimistic about costs when doing the development estimate (48:13).
>
> Inflation Dividend. During the late 1970s, inflation outran program funding requirements. During the early 1980s, the rate of inflation declined, and the DoD (and many other forecasters) overestimated inflation. This resulted in program overfunding in then-year dollar terms. Again, this made it seem like there was less cost growth. (48:13)
>
> Programs Not Included. During the 1980s, there were several major "black" programs, particularly those involving Stealth technology. These programs were not included in cost growth estimates, but the DoD is currently trying to include the costs even of sensitive programs wherever possible. (48:13)

Summary

In this chapter literature search was conducted to gain more insight into the role of cost estimating in the weapon acquisition life cycle and the source selection processes and to explore the reasons for cost growth and some of the methods currently used to control it. The literature suggests that there has been a decrease in cost growth from the 1950s to the 1970s. These decreases can be attributed to such measures as the Packard Initiatives and increased competition. Despite positive trends over the past three decades, current research indicates that the trend was reversed in the 1980s.

III. Methodology

Chapter Overview

This chapter explains the methodology used to answer investigative questions one through three from Chapter I. The data collection procedures and methods of analyzing the data are discussed along with an explanation of how the data was used to predict the range of potential cost growth.

Factors Contributing to Cost Growth

The first question to be answered was, "What are the major sources of cost growth in the development of weapon systems?" A review of the literature concerning cost growth revealed several factors considered to be contributors to cost growth. As mentioned in Chapter II, some of these factors are beyond the control of the Defense establishment. The controllable cost factors identified in the literature reviewed included unrealistic inflation estimates, poor cost estimates, lack of competition among defense contractors, high-risk system design, poor management, changes in weapon systems specifications, unrealistic performance and cost schedules, variability in past cost data, concurrence of the development and production efforts, and technical advances (1) (27) (28) (35) (42) (46) (47). Since the writing of some of the literature, laws and changes in acquisition policies have curtailed some of the problems identified in the literature. For example, lack of competition among contractors is not one of the problems mentioned in the later literature. A Rand comparison of ten systems found evidence that competition led to modest improvements in system performance and on-schedule delivery by contractors, and had substantially lowered real cost growth (35:28). To obtain a timely analysis of those factors considered to be major contributors of cost growth the expert judgement of a panel of cost analysts from Aeronautical Systems Division (ASD) was enlisted. The panel consisted of the following individuals from Aeronautical Systems Division, Research and Cost Division, Directorate of Cost, Deputy for Financial Management and Comptroller:

James L. Adams, Cost Analyst

Charlie Clark, Cost Analyst

Donna Kinlin, Cost Analyst

William H. Kugel, Chief Source Selection

Robert Schwenke, Chief Research/Methods Branch

Kenneth Sullivan, Capt, USAF, Cost Analyst,

A two step process was used to identify those cost factors deemed to be significant contributors to unanticipated cost growth. Step one, entailed identifying those factors that are considered to be contributors to cost growth, based on the literature search and the opinion of selected members of the cost panel. In the second step, the factors which were identified in step one were ranked by the cost panel to determine the three top factors which contribute to cost growth. The members of the cost panel were asked to give the three factors they believed to be most significant drivers of cost growth a rank of one. The decision to rank the top three factors as number one was based primarily on the information gained through the literature search. Throughout the literature the authors did not commit to any one factor as most important, but usually considered a collaboration of factors which were most important for a given time. Secondly, it was the consensus of the preliminary cost panel that concentrating on three or four factors considered to be significant drivers of cost growth would be most beneficial to the study. The author decided on three factors due to the limited data base available. All other factors were ranked consecutively beginning with number four.

Data Collection

As stated in Chapter I, this research considers major and non-major weapon system acquisitions started after 1980 with at least three years of development. The following information was gathered on each of the systems:

1. The most probable cost (MPC) estimate.

2. The actual development/procurement cost or latest estimate if the program is not complete. This cost will be considered the current estimate whether actuals or an estimate.

3. The technical risk, configuration stability, and schedule variance.

All costs were collected in then year dollars to capture the net effect of all cost growth, including inflation. The only adjustments made were for quantity. When the current estimate (CE) quantity is different from the MPC estimate, the quantity estimated at the time of the MPC will be used as the baseline and the CE will be adjusted up or down accordingly. For example, if the quantity of systems to be acquired was originally projected at five and the current estimate allows for three, the current estimate will be adjusted to reflect five systems.

Quantity Adjustment. Quantity adjustments were accomplished in two ways. One method was employed for Selected Acquisition Report (SAR) programs whose quantities were the same in the MPC estimate and the development estimate, and another method for non-SAR programs and SAR programs whose MPC and SAR development estimate quantities differ.

SAR Programs, MPC Quantity Equals DE Quantity. For these programs the CE was simply adjusted up or down by adding the dollar amount attributed to a quantity change reported in the 1990 SAR. This method of adjusting SAR programs is explained in the Rand 1979 study entitled

Acquisition Policy Effectiveness: Department of Defense Experience in the 1970s:

> . . . Thus, if the production quantity has been reduced since DSARC II (a common occurrence), an addition to the CE is required to bring the program cost back up to what it would be if the originally programmed quantity were to be procured; if the production quantity has been increased, a reduction of the CE is required. This is accomplished simply by deleting the cost change attributed in the program's SAR to quantity variance. (35:80)

This method was also employed by the Management Consulting and Research, Incorporated, in their analysis of DoD weapons system cost growth (43:6).

Non-SAR Programs and SAR Programs Whose DE and MPC Quantity Differ. For the non-SAR programs and the SAR programs whose DE quantity differed from the MPC, the quantity adjustment was made by computing the product improvement curve and first unit cost (T_1) for the CE using ICLOT. ICLOT is a computerized program which uses regression analysis to determine the slope and T_1 values for either a unit or cumulative average curve when the lot size and the cost per lot are known (20:7-33). The unit curve formulation was used in this research. The costs per lot are the recurring costs in constant year dollars. The T_1 and slope generated, were then used to calculate the cost which would have been incurred if the quantities outlined in the MPC were still in effect. These cost were derived using ICPRO, a computerized program which "computes projected values under the unit cost improvement curve theory given a slope and T_1 or the average cost of a lot, and its first and last units" (20:7-32). The adjusted quantity costs resulting are recurring cost in constant year dollars. The percentage of recurring cost to total cost of the CE was used to calculate the total cost of the adjusted estimate. The December 1989 OSD Weighted Inflation Rates (Appendix C) were used to convert the constant year to then year dollars.

Calculating the Cost Factor (CF)

To determine the amount of cost growth the adjusted current estimate (CE) was divided by the MPC. The resultant number is the cost factor (CF).

$$CF=\frac{CE_{(d,p)}}{MPC_{(d,p)}} \tag{2}$$

where

d = development
p = production

A CF greater than one implies there was some cost growth in the program. A CF of less than one implies a reduction in cost and a CF of unity implies there was no change in the cost.

Cost/Schedule/Configuration Trends Analysis

Before accomplishing the analysis based on the three factors contributing to cost growth identified above, the programs were analyzed to determine if any trends could be found based on the dollar value of a program and its cost factors (CFs) or ECO percentage. This analysis was accomplished by graphically plotting the CF and ECO dollars against cost in the production and development. Throughout this research, the development and production efforts are treated separately.

Methodology for Data Analysis

The four step process below was used to analyze the data based on the three cost factors identified.

Step 1. First, all the observed weapon systems were categorized as having high or low technical risk and being of stable or unstable configuration. The data on the technical risk was obtained from the cost documentation, discussion with program managers, and cost analysts who worked the programs. Systems were considered to be of either high of low technical risk. There were no provisions made for medium risk.

Step 2. The technical risk was then compared to the configuration stability. The configuration stability assessment was made based on the percentage of ECO dollars to the most probable cost estimate. According to The AFSC Cost Estimating Handbook, ECO dollars are ". . . widely accepted throughout the Air Force as representing that amount of money in a program specifically set aside for uncertainty" (20:13-32). The higher the uncertainty the higher the percentage which must be set aside. Based on this premise, it stands to reason that a program with a higher ECO percentage has less certainty and thus, less configuration stability. The data base was divided in half, based on the percentage of ECO dollars to the most probable cost estimate. Placing those programs with higher ECO dollar percentages in the low stability category and those with the lower percentages in the high configuration stability category. The four possible combinations of technical risk and configuration stability are represented in Table 3.

Table 3

Technical Risk/Configuration Stability

Configuration Stability	Technical Risk: High	Technical Risk: Low
High	I	II
Low	III	IV

Step 3. The next step in the analysis was to add the schedule assessment. Quadrants I through IV above were further broken down based on the schedules experienced by the programs in each quadrant. The schedule assessment was analogous to the convention used in the <u>Independent Schedule Assessment Handbook</u> (49). The Handbook defines a low impact on schedule as one which results in a slip of less than one

month (49:50). A medium impact is one which results in a slip of at least one month but less than three (49:50), and a high impact is one which results in a slip of greater than three months (49:50). In this research the programs were divided into two categories, low schedule impact (Category A) and high impact (Category B), with approximately half in each category. The development effort schedule assessment was determined based on completion of Development, Test and Evaluation (DT&E). The production effort schedule assessment was based on the first production delivery schedule.

There are eight possible combinations of schedule, configuration, and technical risk which are represented in Table 4 below. All eight regions of Table 4 were considered to be pertinent to this research, due to the many uncertainties present in the acquisition environment.

Table 4

Technical Risk, Configuration Stability, and Schedule Assessment

Schedule Assessment		I	II	III	IV
	A	IA	IIA	IIIA	IVA
	B	IB	IIB	IIIB	IVB

Step 4. Once the systems were assigned to their respective grids, median CFs were calculated for each category. By definition,

> The median of a set of observations is the middle one if the number of observations is odd and the average of the middle pair if their number is even when these observations are arranged in increasing order. (44:12)

The median was chosen to represent the estimated potential cost growth because it is a more robust measure of central tendency than the mean and is less likely to be unduly influenced by extreme high or low cost factors. According to Newbold, the median is often preferred in circumstances where it is inappropriate to give much weight to extreme observations (44:13).

Range of Potential Cost Growth Around the MPC

The last step in the analysis, was to determine how the information obtained above could be used to estimate a range of potential cost growth around the MPC in answer to investigative question #3. In the following paragraph the method for obtaining the potential cost growth range is explained.

The Median CF of the category to which the MPC is assigned can be viewed as an estimate of the most probable cost growth for that program. The upper and lower bound CFs for the given category will be used to determine the range of cost growth around the most probable cost estimate.

Summary

This chapter explained the methodology used to answer the investigative questions posed in Chapter I. To answer investigative question #1, a literature search was conducted in Chapter II to identify the factors which contribute to cost growth. A panel of experts was employed to supplement the literature search and ensure the factors identified were applicable in today's environment. To answer investigative question #2, a method of accessing a program based on the three factors identified in investigative question #1 was developed. Lastly, the method for defining a range of potential cost growth around the most probable cost estimate was discussed. The methodology set forth in this chapter will be conducted and analyzed in Chapter IV followed by conclusions and recommendation for further studies in Chapter V.

IV. Analysis of Data

Chapter Overview

In this chapter three factors considered to be major contributors to cost growth are identified by a panel of six cost analyst from Aeronautical Systems Division, and applied to a data base consisting of sixteen systems. The analysis is followed by a discussion of the findings.

Factors Contributing to Cost Growth

In step one, William Kugel, Charlie Clark, Mike Seibil, Dr. Richard Murphy, and the author, met to discuss the reasons for cost growth contained in the literature and to add to this list any items not covered. Once the group felt all the significant sources of cost growth were exhausted, the following list of factors contributing to cost growth was derived:

1. Contractors experience in the area of acquisition.

2. Contractor's familiarity with the Government's way of doing business.

3. Risk due to technical advances.

4. Time and development schedule for the program.

5. Degree of concurrence between Engineering and Manufacturing Development (EMD) and Production.

6. Whether or not the system is within the range of historical data.

7. System requirements/configuration stability.

8. The existence or nonexistence of actual cost by functionality and/or work breakdown structure (WBS) for analogous systems.

9. Schedule slippage or variations.

In the following paragraphs the meaning of these nine factors as discussed by the cost panel will be explained.

1. Contractors Experience in the Area of Acquisition.

This factor implies that if contractors had experience in the area of acquisition that experience can be applied to the new system, thus reducing risk.

2. Contractor's Familiarity with the Government's Way of Doing Business.

The premise underlying this factor is, if contractors understood the peculiarities of doing business with the government the cost of monitoring the contract and correcting deficiencies would be minimal.

3. Risk Due to Technical Advances.

This factor considers the state-of-the-art of the technology of the system being produced. The relationship between technical advance and uncertainty is considered to be proportional; the more technically advanced the system, the more complex and the greater the uncertainty.

4. Time and Development Schedule for the Program.

Time and development schedule in this context refers to the amount of time the contractor says it will take to complete the project.

5. Degree of Concurrence Between EMD and Production.

This factor attempts to capture the amount of cost growth due to the amount of overlap of development and production. A program which begins production before completion of development tests is apt to experience more cost growth than one that begins production only after final testing.

6. Whether or not the System is Within the Range of Historical Data.

This factor is of concern when using the parametric and analogous estimating technique. Parametric estimating, as defined in Chapter II, often depends on cost estimating relationships and the analogous method looks at the new system as compared to a previous system. CERs are often calculated using regression techniques. There are some cautions which must be made when using regression analysis. Number one, as the item being estimated moves away from the center of the data, the width of the prediction interval generally increases. Secondly, if the system, the independent variable, lies far beyond the range of past data,

> . . . extreme caution should be exercised since one cannot be sure that the regression function which fits the past data is appropriate over the wider range of the independent variable. (45:85)

7. System Requirements/Configuration Stability.

In the development arena change is constant. This factor considers cost growth that is the result of configuration changes.

8. The Existence or Nonexistence of Actual Cost by Functionality and/or WBS for Analogous Systems.

If the analogous system can be broken down by functionality and/or work break down structure with the benefit of actual costs, the resultant cost estimate should be able to predict cost more accurately than if this were not the case. A major assumption is that the analogous system was correctly identified.

9. Schedule Slippage or Variation.

Unlike number three above, which refers to the number of development years, this factor refers to cost growth due to schedule stretch-outs or compressions.

Three Major Contributors to Cost Growth. As discussed in Chapter III, after identifying the factors the next step was to have the members of the panel rank the factors from one to nine allowing the top three factors to share the rank of one. The results of the ranking process are contained in Table 5. The numbers far left column represent the nine cost growth factors (CGFs) identified above. The column headings are the rankings from 1 through 9. The numbers in the body of the table represent how many of the six panel members ranked the identified factor at a given level. The results of the ranking clearly indicates that configuration stability (#7) is thought to be a major factor influencing cost growth. Six of the six panel members ranked this factor number one. Four of the six cost analysts ranked risk due to technical advances (#3) as number one. The other two members;

Table 5

Ranking of Factors Contributing
to Cost Growth

CGF #	Ranking 1	4	5	6	7	8	9
1	1	1	1		2		1
2	1	1	1				3
3	4				2		
4		1	1	2		2	
5		1		2	2		1
6		2	2			2	
7	6						
8							
9	3	1		1			

however, ranked technical risk as number seven. The analysts who ranked risk due to technical advances as number seven, acknowledged that technical risk is an important consideration when discussing cost growth; however, they felt that with the current state of technological maturity, technical risk is not a major factor in today's environment. The third factor receiving high ranks from the cost panel was schedule slippage or variations. Fifty percent of the panel members felt this was a major factor and one panel member ranked it fourth. Though there were some disparities in the ranking; configuration stability, technical risk, and schedule variations were the three cost factors determined by the panel cost analysts to have the most significant impact on cost growth in today's environment.

Data Collection

Currently, a central data base does not exist which lists all the weapons systems procured at Aeronautical Systems Division over the past decade. To assist in identifying the applicable system, William Kugel, and the Research and Cost Division, Directorate of Cost, provided the initial list of systems procured in the last decade. The resultant list consisted of thirty programs. The list was reviewed to ensure all systems had completed at least three years of development and that all programs were actually procured in the 1980s. Those systems which did not fit the three year development criteria were immediately discarded from the list. Additional systems were deleted due to unavailability of data. The final list of programs used in this research is contained in Table 6. Appendix A contains a description of the programs.

Table 6

Programs Used in the Research

AC-130 Gunship	C-130
Advance Cruise Missile	[illegible]at Talon
Air Force One	[illegible]se Missile Mission Control Aircraft
Advance Tactical Air Reconnaissance System	F-111 Digital Flight Control System
B-1B Simulator	LANTIRN
C-17 (C-X)	LANTIRN SIMULATOR
C-17 Aircrew Training System	SRAM II
C-17 Maintenance Training Device	

Tables 7 and 8, contain the data collected on the selected programs for the development and the production effort respectively. The MPC estimates in the tables were obtained from Source Selection cost documentation found in ASD's Cost Library. The current estimates were taken from the latest system program office approved cost estimates and from the December 1990 Selected Acquisition Reports (SARs) and adjusted for quantity as needed.

Table 7

Development Effort ($ in Millions)

SYSTEM	MPC $	CE $	CF	SCHED VAR	TECH RISK	ECO %
AC-130	260.50	265.03	1.02	12 mos	H	0.01
ACM	1492.40	1755.20	1.18	4 mos	H	0.04
AF-1	48.90	40.40	0.83	2 yrs	L	0.01
ATARS	179.83	287.30	1.60	22 mos	H	0.08
B1B SIM	109.22	142.87	1.31	2 yrs	L	0.30
C-17	3567.42	5595.30	1.57	15 mos	L	0.03
C-17 ATS	57.49	75.43	1.31	6 mos	L	0.07
C-17 MTD	54.89	93.44	1.70	11 mos	L	0.36
C130 ATS	12.6	13.03	1.03	0 mos	L	0.12
COMBAT T	46.3	104.30	2.25	19 mos	H	0.14
CMMCA	54.50	58.04	1.06	15 mos	L	0.03
F111DFCS	59.50	63.92	1.07	1 mos	L	0.40
LANTIRN	548.90	601.30	1.10	17 mos	H	0.03
LANTIRN SIM	29.07	28.60	0.98	17 mos	L	0.02
SRAM II	991.94	1267.10	1.28	2 yrs	H	0.10

Of the sixteen systems reviewed, fifteen are represented in the development effort, because the C-20 Aircraft Program is a production only program. The cost factor for Combat Talon is noticeably higher than the other programs because the program was initiated as a production only effort. Some development money was initially included in the MPC estimate to allow for expected redesign work in the production effort. When it became apparent that a more extensive development program was necessary, a full scale development effort was added to the program's baseline. Though this does represent an anomaly, the program was not discarded from the data base, because the intent of the study is to capture all cost growth, including anomalies.

Fourteen systems are represented in the production effort. The Cruise Missile Mission Control Aircraft does not include a production effort. The Advanced Tactical Air Reconnaissance System (ATARS) production effort was not included due to complications in the current estimate, which are currently being reworked.

The Advanced Cruise Missile (ACM), C-17 aircraft, LANTIRN, and SRAM II programs all experienced a quantity reduction from the MPC estimate to the production estimate. All of these programs are Selected Acquisition Report (SAR) programs and all, except the C-17, have the same production quantities in the development estimate baseline reported in the SAR and the MPC estimate. In these cases, the current estimates were adjusted back up to the original quantity by adding the decrease due to quantity change reported in the SAR to the current estimate. This method could not be used for the C-17 program, because the MPC estimate differed from the development estimate. The development estimate (DE) as defined in Chapter II, is the baseline to which many programs are compared, normally developed late in the Demonstration and Validation Phase. The MPC in the C-17 program represents a quantity of 132 units, while the DE represents a quantity of 210 units. The latest SAR reports a quantity reduction of 90 units and an associated cost reduction of $11039 million. If the current estimate of $29351.9 million were adjusted for quantity by simply adding back in the reduction associated with the quantity change, the adjusted current estimate would be $40390.9 million. However, if this current estimate were compared to the MPC to determine the cost growth the amount would be artificially high, because the MPC represents 132 units versus 210. The current estimate was normalized to reflect a quantity of 132 production units. This normalization was accomplished by first calculating a cost improvement curve for the current estimate quantities, using ICLOT to develop the theoretical first unit cost (T_1) and slope. Once the slope and T_1 were calculated ICPRO was used to estimate the cost for 182 units using the same spend profile as the MPC estimate. The details are contained in Appendix B. Table 8 contains the adjusted current estimates.

Table 8

Production Effort ($ in Millions)

SYSTEM	MPC $	CE $	CF	SCHED VAR	TECH RISK	ECO
AC-130	565.10	630.28	1.12	12 mos	H	0.07
ACM	5106.80	5805.30	1.14	5 mos	H	0.01
AF-1	306.90	314.78	1.03	2 yrs	L	0.04
B1B SIM	109.22	214.58	1.96	2 yrs	H	0.30
C-17	20160.61	36973.65	1.83	15 mos	L	0.03
C-17 ATS	233.33	231.96	0.99	6 mos	L	0.02
C-17 MTD	57.05	93.44	1.64	0 mos	L	0.35
C-20	256.5	197.10	0.77	0 mos	L	0.00
C130 ATS	22.26	24.33	1.09	0 mos	L	0.07
COMBAT T	1341.40	1730.20	0.29	7 mos	H	0.00
F111DFCS	54.60	73.30	1.34	3 mos	L	0.44
LANTIRN	3274.30	3554.10	1.09	15 mos	H	0.01
LANTIRN SIM	15.89	25.30	1.59	15 mos	L	0.04
SRAM II	1211.62	1492.30	1.23	2 yrs	H	0.03

Cost Factor/Engineering Chang Order Trends

The data from Tables 7 and 8 were analyzed to determine if a relationship exists between the dollar amount of a program and the cost growth and engineering change order percentages experienced by the program. Figures 3 through 6, provide a graphical depiction of this analysis.

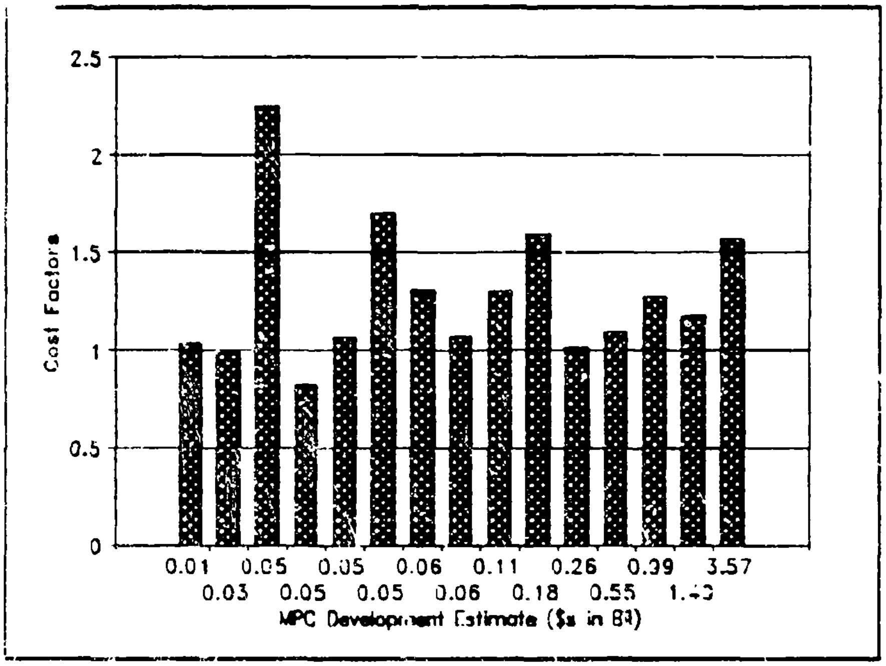

Figure 3. Development Cost Factor/Cost Comparison

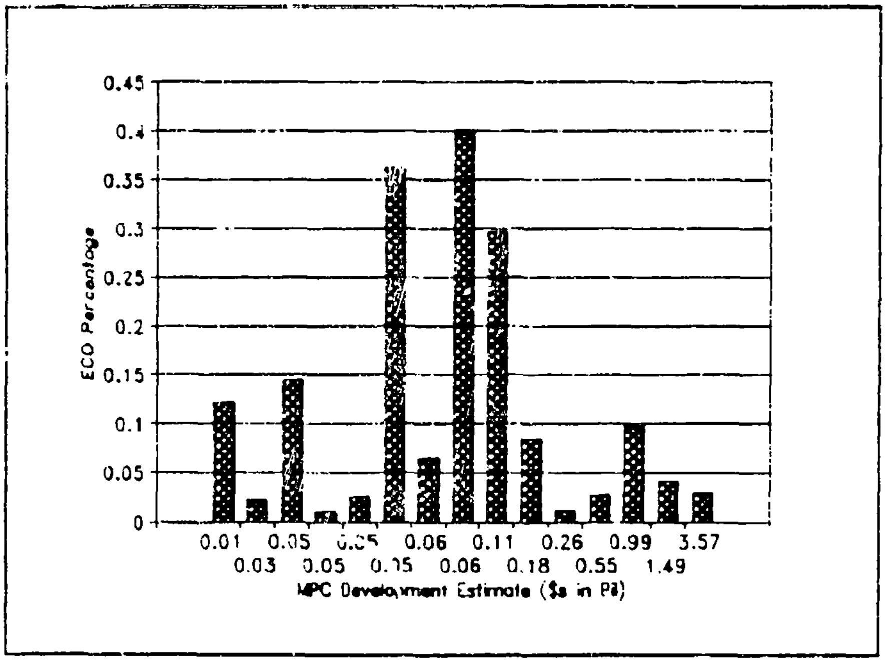

Figure 4. Development ECO/Cost Comparison

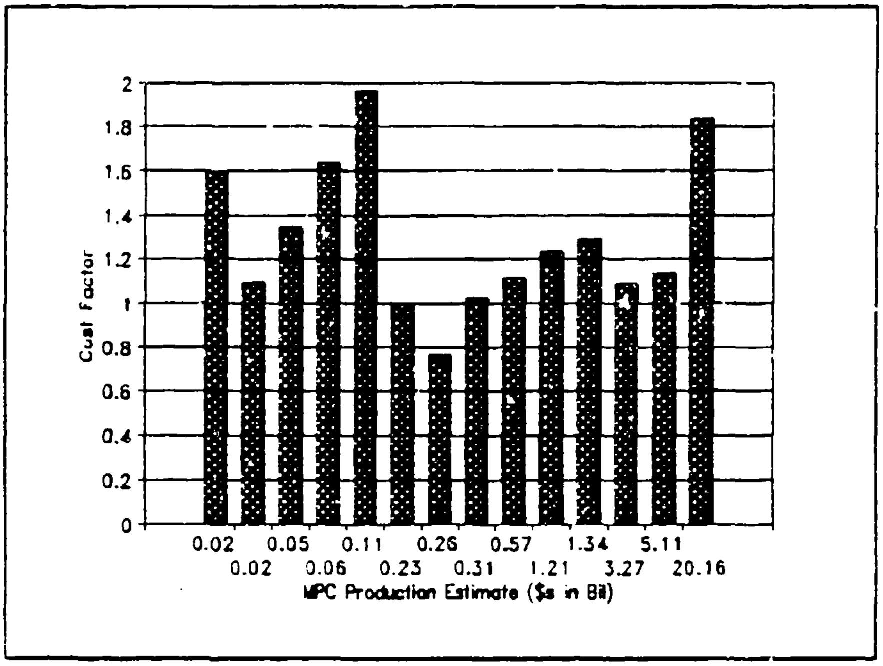

Figure 5. Production Cost Factor/Cost Comparison

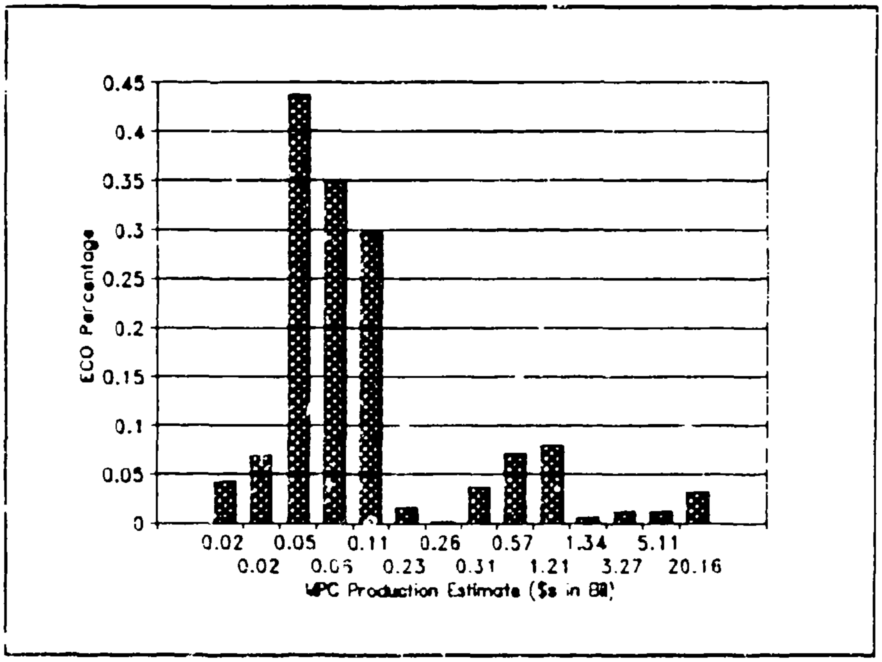

Figure 6. Production ECO/Cost Comparison

From Figures 3 and 5, there does not appear to be a relationship between the size of a program and the cost factor in either the development or the production efforts. However, a relationship does appear to exist between the total cost of the program and the ECO percentage. This trend is not as apparent in the development effort as it is in the production effort; however, it appears that the larger programs tend to have a smaller percentage of engineering change orders (Figures 4 and 6). Despite this trend, the ECO percentages were considered to be good indicators of configuration stability, based on the assumption that ECOs represent the uncertainty in an estimate (20:13-32) and that the greater the uncertainty the greater the percentage of ECO required to cover changes and rework (20:13-36).

Data Analysis

The first step in the data analysis, as described in Chapter III, was to categorize the data based on technical risk and configuration stability. Tables 9 and 11 depict the technical risk and configuration stability of the development and production efforts respectively.

Observations from Table 9 revealed that the high technical risk/low configuration stability category tended to have the highest cost factors, while the low technical risk/high configuration stability category has lower cost factors.

Table 9

Technical Risk/Configuration Stability
Development Effort

Technical Risk

Configuration Stability	High: System	High: CF	Low: System	Low: CF
High	AC-130 Gunship	1.02	C-17	1.57
	ACM	1.18	CMMCA	1.06
	LANTIRN	1.10	LANTIRN Sim	.98
			C-17 ATS	1.31
			AF-1	.83
Low	SRAM II	1.28	B-1B Sim	1.31
	ATARS	1.60	F-111 DFCS	1.07
	Combat Talon	2.25	C-17 MTD	1.70
			C-130 ATS	1.03

It appeared that the high technical risk programs had higher CFs than the low technical risk programs. To test this a comparison was made between the two categories. The median CF for the high technical risk programs was 1.23 while the median CF for the low technical risk programs was 1.07; consistent with expectations. A similar comparison was made between low and high configuration stability. The median CF was 1.08 for programs with high configuration stability and 1.31 for those programs with low configuration stability. Once again the results were consistent with expectations.

A look at the median cost factors (Table 10) for each quadrant of Table 9 reinforces the trends observed above.

Table 10

Technical Risk/Configuration Stability
Median Development Cost Factors

Technical Risk/ Config. Stability	Median CF
High/High	1.10
Low/High	1.06
High/Low	1.60
Low/Low	1.19

The median CF for Quadrant I, high technical risk/high configuration stability is 1.10; Quadrant II, low technical risk/high configuration stability is 1.06; Quadrant III, high technical risk/low configuration stability is 1.60; and quadrant IV, low technical risk/low configuration stability is 1.19. From these observations, configuration stability appears to have a greater influence on cost growth than technical risk. In both cases where configuration stability is unfavorable (low), the highest median cost factors are observed; 1.60 and 1.19. On the other hand, the median CF is relatively low in one instance where the technical risk is high.

Several observations can be made from a precursory look at Table 11. One of the most notable is that the low technical risk/high configuration stability category has the lowest cost factors; 0.77, 0.99, and 1.03. This category also contains one of the highest cost factors in the data base.

Table 11

Technical Risk/Configuration Stability
Production Effort

Technical Risk

Configuration Stability	High: System	High: CF	Low: System	Low: CF
High	Combat Talon	1.29	C-17	1.83
	ACM	1.14	C-20	.77
	LANTIRN	1.09	LANTIRN Sim	1.59
			C-17 ATS	.99
			AF-1	1.03
Low	SRAM II	1.23	B-1B Sim	1.96
			F-111 DFCS	1.34
	AC-130 Gunship	1.12	C-17 MTD	1.64
			C-130 ATS	1.09

Another observation is that the high technical risk category overall, appears to have lower cost factors than the low technical risk categories. The median cost factor of the high technical risk category is 1.14 compared to 1.34 for the low technical risk category. There may be several reasons why the higher risk programs experience less cost growth than the lower risk programs in the production effort. One of which could be extra attention placed on proper design of programs thought to be of higher risk. The median cost factors of the high and low configuration stability categories are 1.12 and 1.29 respectively indicating that programs with high configuration stability tend to experience less cost growth than those with low configuration stability. Table 12 depicts this trend. The programs with low configuration stability have the highest median cost factors. This suggests that configuration stability is perhaps a more significant contributor to cost growth in the production effort. In the development effort, the smallest median cost factor was reported in the low technical risk/high configuration stability category.

Table 12

Technical Risk/Configuration Stability
Median Production Cost Factors

Technical Risk/ Config. Stability	Median CF
High/High	1.14
Low/High	1.03
High/Low	1.18
Low/Low	1.49

One of the major differences in the development and production estimates is in the category which has the highest cost factor. In the development estimate, the high technical risk/low configuration stability category had the highest median CF, at 1.60. In the production effort low technical risk/low configuration stability had the highest median CF of 1.49. From these observations it appears that high technical risk is more important to cost growth during the development effort; than in the production phase. The next step in the analysis was to incorporate the schedule factor into the equation.

Based on the schedule variations contained in Tables 7 and 8, low schedule assessment was defined as one which results in a slip of less than six months for the purpose of this study. Tables 13 and 14, refer to those programs that are no more than six months behind schedule as Category A, and those that are more than six months behind schedule as Category B. The quadrants I through IV represent the four scenarios from Tables 9 and 10. Quadrant I represents high technical risk/high configuration stability, Quadrant II represents those with low technical risk/high configuration stability; Quadrant III, high technical risk/low configuration stability; and Quadrant IV, low technical risk/low configuration stability.

Of the fifteen development systems, only four were less than six months behind schedule. Seventy-four percent of the programs were greater than six months behind schedule in the development effort and sixty-four percent (nine out of fourteen) of the production effort were either greater than or projected to be greater than six months behind schedule. The high technical risk/low configuration stability/low schedule impact category was not represented in either [illegible] opment nor the production efforts.

[illegible] calculated for each cell [illegible] and are presented in Tables

Table 13

Technical Risk, Configuration Stability, and Schedule Assessment, Development Effort

Quadrants

Schedule Assessment	I System	I CF	II System	II CF	III System	III CF	IV System	IV CF
A	A[illegible]	1.18	C17 ATS	1.31			C130 ATS	1.03
							F111 DFCS	1.07
B	AC130	1.02	C17	1.57	SRAM II	1.28	B1B Sim	1.31
	LANTIRN	1.10	CMMCA	1.06	ATARS	1.60	C17 MTD	1.70
			LANTIRN Sim	.98	Com Tal	2.25		
			AF-1	.83				

Table 14

Technical Risk, Configuration Stability, and Schedule Assessment, Production Effort

Quadrants

Schedule Assessment	I System	I CF	II System	II CF	III System	III CF	IV System	IV CF
A	ACM	1.14	C20	.77			C130 ATS	1.09
			C17 ATS	.99			F111 DFCS	1.34
B	Com Tal	1.29	C17	1.83	SRAM II	1.23	B1B Sim	1.96
	LANTIRN	1.09	LANTIRN Sim	1.59	AC130	1.12	C17 MTD	1.64
			AF-1	.83				

15 and 16 based on the technical, configuration, and schedule assessments. The upper bound CFs in the tables represent the highest CF contained in a given category. The lower bound CFs are simply the lowest CF in the category. In the three cells containing only one observation, the observation is recorded in the table as the median.

Table 15

Development Potential Cost Growth Range

Tech Risk	Config Stability	Schedule Impact	Upper CF	Med CF	Lower CF
High	High	Low		1.18	
High	High	High	1.10	1.06	1.02
Low	High	Low		1.31	
Low	High	High	1.57	1.02	.83
High	Low	High	2.25	1.60	1.28
Low	Low	Low	1.07	1.05	1.03
Low	Low	High	1.70	1.51	1.31

The lowest median CF in the development effort was 1.02 in the low technical risk/high configuration stability/high schedule impact category. The category with the highest median CF is the high technical risk/low configuration stability/high schedule impact category, at 1.60. The two highest median CFs reported in Table 15 both have high schedule risk and low configuration stability. Of the four categories containing high schedule impact, two have the highest median CFs, 1.60 and 1.51, while the other two have two of the lower CFs, 1.02 and 1.06. In the instances where a high schedule risk is associated with a low median cost factor, it is coupled with high configuration stability. When coupled with low configuration stability, the median CF tended to be high. There was no apparent relationship between technical risk and the schedule impact. One observation which can be noted; however, is that of the three factors configuration stability appears to have the most influence over cost growth. It appears that if either an unfavorable schedule or technical risk assessment is combined with an unfavorable configuration assessment, the median cost factor will be high. The converse does not appear to be true. If the configuration stability assessment is high (favorable), combining it with a program with low technical risk or a low schedule risk will not guarantee a low cost factor. In fact with all factors reporting favorably, the cost growth factor in scenario three (low technical risk, high configuration stability, low schedule risk) was 1.31, one of the highest reported in the table.

From Table 16, the highest median CF reported in the production effort was 1.80, which occurred in the scenario where the schedule and configuration assessments were unfavorably. Schedule risk and configuration stability do not appear to have the same correlation witnessed in the development effort. The second highest median CF in the production effort is the same scenario which produced the lowest median CF in the development estimate, in which technical risk and configuration were reported favorably, while the schedule was unfavorable. In all instances where the schedule risk was high the median CF was at least 1.18. The median cost factor overall seems to be higher in the production effort.

Table 16

Production Potential Cost Growth Range

Tech Risk	Config Stability	Schedule Impact	Upper CF	Med CF	Lower CF
High	High	Low		1.14	
High	High	High	1.29	1.19	1.09
Low	High	Low	.99	.88	.77
Low	High	High	1.83	1.59	.83
High	Low	High	1.23	1.18	1.12
Low	Low	Low	1.34	1.22	1.09
Low	Low	High	1.96	1.80	1.64

Calculating the Range of Cost Growth

The first step in determining the range of potential cost growth is the completion of the MPC estimates by the source selection cost panel. Once the estimates are complete, the cost analyst assigns each MPC estimate to one of the categories in Table 4 based on the technical, schedule, and configuration risk assessments used by the analyst while developing the estimate. The median CF, upper and lower bound CF from Table 15 and 16 can be used to gain a feel for the range of cost growth experienced in recent programs.

Summary

In this chapter nine factors contributing to cost growth were analyzed and three were chosen by a panel of experts to be the most significant; technical risk, schedule risk, and configuration stability. The most probable cost estimate, current estimate, schedule variation, and the percentage of engineering change order costs to the most probable cost estimate were collected from a data base of sixteen systems procured in the last decade. The cost growth of the systems was analyzed based on the three factors above to determine if potential cost growth can be forecasted based on an assessment of the three factors. The conclusions to this analysis and recommendation for further study are contained in the next chapter.

V. Conclusions and Recommendations

Chapter Overview

The objective of this research was to develop a method of predicting a range of potential cost growth around the most probable cost estimate. The author sought to develop this method by researching the cost growth experienced in recent programs and categorizing these programs based on several factors. These factors were derived from a literature search and ultimately narrowed down to three factors by a panel of cost analysts. In the chapter the results of this research will be discussed by answering the investigative questions presented in Chapter I. This discussion will be followed by recommendations for further study.

Investigative Question #1

Investigative question #1 seeks to determine the sources of cost growth in the acquisition of weapon systems. The answer to this question was pursued using a two step process. The first step involved a literature search to ascertain what factors are considered to be jor drivers of cost growth. One of the conclusions obtained from the literature search is that the factors contributing to cost growth are not constant, but change over time. The dynamic environment emphasized the need to understand the factors affecting cost growth in the current environment when trying to control cost growth.

In the second step a list of factors contributing to cost growth was generated through the combined efforts of the literature and working group of five cost analysts. This list of factors was individually ranked by a panel of cost analysts to determine the three factors which are considered to be the most significant drivers of cost growth in today's environment. The three items identified were technical risk, configuration stability, and schedule risk. Once these factors were identified the next step was to determine how this information could be used to help estimate potential cost growth; the question asked in investigative question #2.

Investigative Question #2

In order to answer investigative question #2 sixteen programs were analyzed to determine if there were any correlations between the cost growth experienced in the program and the three factors determined to be major cost drivers. Several implications can be made from the data. In the following paragraphs they will be explained as it relates to the development and the production efforts.

Observations in the Development Effort. When the effect of all three factors are considered together in the development effort, configuration stability tends to have more influence on cost growth than the other factors. The analysis suggest that significant cost growth should be expected if the program is operating in an environment with low configuration stability and high schedule risk. Though high configuration stability does not guarantee minimal cost growth, the cost growth experienced in these programs tend to be less on average than those with low configuration stability.

It also appears that reducing technical risk will not significantly decrease cost growth if there is a high probability that the schedule will slip six months or more. However, to minimize potential cost growth the configuration must be stabilized as early as practicable in the development effort since the programs with higher configuration stability tended to experience less cost growth on average, regardless of the behavior of technical risk and the schedule assessment.

Observations in the Production Effort. When all three factors are considered together configuration stability does not appear to be as influential in the production effort as it did in the development effort. Schedule risk, however appeared to be the most influential cost driver. In all instances where the schedule risk was high, the cost growth exceeded eighteen percent. When configuration stability and technical risk were viewed apart from schedule risk:

however, configuration stability was a major factor influencing cost growth.

This suggests that there is a stronger relationship between configuration stability and schedule in the production effort. Therefore, in order to minimize cost growth in the production effort the configuration must be stable and the schedule must be realistic. Technical risk, is not as influential in the production effort as configuration stability and schedule.

The next step in the analysis was to determine how this information can be utilized by cost analysts to help control cost growth. This issue will be discussed in the following paragraphs.

Investigative Question #3

This investigative question sought to determine how the information used above could be used to help estimate potential cost growth around the most probable cost estimate. The cost analyst can use the information gained in this research to gain a feel for the range of cost growth experienced in similar programs, by observing the cost growth histories in Tables 15 and 16 in Chapter IV. Due to the limited data set, no statistical inferences can be obtained from the data. With a larger data set and a significant number of observations in each cell the method could provide some statistical intervals for potential cost growth.

Recommendations for Further Research

It is strongly recommended that more research be accomplished in this area. Though the literature suggests that there are major differences in the procurement environment between periods, the applicable data set can be significantly increased by normalizing for these differences. Normalizing for the differences, such as longer development cycles in the eighties, can also eliminate the problem of dealing with such current data. This research focused on programs that were initiated in the last decade have been in development or production for at least three years. One of the drawbacks of using such current data is that estimates had to be used instead of actuals. Though some of these programs are mature, there are many factors which can change the current cost growth trends. Just as some of the programs are mature, there are some which are relatively young and may not have experienced the most significant cost growth. Ideally it would better to deal with actuals, because in dealing with actual costs over the entire program you do not run into the problem of comparing systems at different maturity levels. Future research would benefit from observing the cost growth behavior of programs with actual costs available.

Another issue raised during the research was the apparent relationship between the dollar value of the program and the number of engineering change orders (ECOs).

It seemed that the smaller programs had a higher percentage of ECOs. Suggesting that future studies should segregate programs by size.

The number of programs greater than six months behind schedule indicates that there is a dire need for better schedule assessments. An analysis of the various reasons for schedule slippage can provide insight into the areas where emphasis must be placed to improve the overall schedule performance.

The MPC estimates can usually be classified as Category IV -- no actuals available, system description is fair to good, some data available for analogies, factors, parametrics, etc., or Category V -- uncertain system description and data available for analogies, factors parametrics, etc. are sparse or have limited value to system being estimated. The range of cost growth around the MPC estimate provides a method of quantifying the confidence level of these two categories. Another area for potential research involves finding the range of cost growth for each of the five categories of confidence defined in AFSCR 173-[illegible], and in Chapter III of this research.

Summary

This research sought to determine a method to estimate the potential cost growth around the most probable cost estimate based on the behavior of three major cost drivers;

technical risk, configuration stability, and schedule risk. The data obtained in this research is useful in providing cost analyst with a rough order of magnitude of what can be expected.

Appendix A: Program Descriptions

AC-130U Gunship (2:2-3)

The AC-130U Gunship program will purchase twelve C-130H airframes which will be converted to side-firing gunships. The gunship will incorporate improved night/adverse weather capability with improved survivability, precision fire support, and worldwide deployment.

The development effort consists of designing, developing, and integrating an avionics suite and a gun suite, including the development of organizational, intermediate, and depot level support equipment.

The production estimate includes procurement of eleven C-130 air vehicles and engines, conversion to the gunship configuration, delivery of organizational, intermediate, and depot level support equipment, training equipment, government furnished equipment, and armament. The development unit will be refurbished into production configuration.

Advanced Cruise Missile (3:3)

The Advanced Cruise Missile (ACM) program improves existing ACM capability while utilizing improved range and low observable capability.

The ACM is an airbreathing, subsonic, air launched, cruise missile encompassing a basically cylindrical fuselage with a sharp nose, chines, body RAM, forward swept pop-out wings, flush inlet and partially shielded exhaust. The ACM satisfies the Strategic Air Command's statement of need for increased range, improved survivability, and accuracy. Production of 1461 of these missiles is planned, of which 120 will be a variant with a classified mission. The variant configuration is the same as the ACM, except for provisioning for a heavier payload.

Advanced Tactical Air Reconnaissance System (4)

The primary mission of the ATARS is to provide near real time reconnaissance. ATARS is composed of a manned reconnaissance effort designated Tactical Air Reconnaissance System (TARS), and an unmanned effort designated Unmanned Air Reconnaissance System (UARS). The program will replace existing reconnaissance film sensors with electro-optical sensors and supporting subsystems to provide near real time reconnaissance capability. TARS includes the TARS sensor upgrade. The UARS will combine the Navy's Mid Range Remotely Piloted Vehicle with some of the elements of the TARS sensor suite and an infrared line scanner.

Air Force One (5:2-4)

The Air Force One (AF-1) program will purchase and modify two commercial widebody Boeing 747 aircraft to replace current Boeing 707 aircraft used for presidential travel. The new AF-1 aircraft's mission is to safely and securely transport the President, his family, staff, guests, security contingent, and the press to any world-wide destination. The aircraft will be certified in accordance with applicable Federal Aviation Regulations.

The development effort incorporates such tasks as design engineering, integration and analysis, and system test and certification. The procurement costs also include training of an initial cadre of Air Force aircrew personnel, delivery of data, an integrated logistics support plan and site conversion.

B-1B Simulator System (7)

The B-1B Simulator System consists of five weapon system trainers, two Mission Trainers, six Cockpit Procedures Trainers, and one Software Support Center to support the B1-B aircraft The simulators will provide the increased visual motion and aural cues for the ground training of Strategic Air Command B-1B aircrew members. Required training tasks include: mission rehearsal training for takeoff and landing, navigation, air refueling, threat analysis/countermeasures, low-level penetration, weapons delivery and emergency procedures. Emphasis will be placed on training that cannot be accomplished in the aircraft and also on integrated crew training. These tasks include those related to safety of flight, emergency procedures, and emergency war order rehearsal.

In the 30 September 1988 cost estimate, the B-1B Simulator System's risk due to technical advances was rated as difficult and the configuration design requirements was considered to be moderately uncertain. The configuration uncertainty of the B-1B Simulator is due to difficulties in the defensive systems of the B-1B aircraft. The B-1B schedule has slipped two years in both development and production.

The purpose of the C-17 aircraft is to modernize the airlift fleet and improve the United States' overall capability to rapidly project, reinforce and sustain combat forces worldwide. The aircraft will augment the C-5 and C-141 in intertheater deployment and the C-130 with intratheater operations. The C-17 is capable of carrying outsize cargo over intertheater ranges into austere airfields. This introduces a direct deployment capability that will significantly improve airlift responsiveness, thereby improving the mobility of the general purpose forces.

In the MPC estimate there were 182 aircraft in the production buy schedule. The 1990 Secretary of Defense directed Major Aircraft Review resulted in the reduction of the total aircraft buy for this program from 210 aircraft in the DE to 120 aircraft in the CE. This reduction was in anticipation of a 25% increase in the Program Acquisition Unit Cost.

Based on the ASD ECO model inputs, the C-17 effort is considered to be of low technical risk. The configuration changes are due primarily to weight reduction made during the development process. The engineering change orders in the development effort totaled $106.2 million in then year dollars. This total was derived by adding the amount of engineering change proposal 40, $67.8 million, and $38.4, the dollar value estimated using ASD's ECO model. The Initial Operational Capability schedule of the first twelve ai raft slipped 15 months; from June 1993 to September 1994.

C-17 Aircrew Training System (8)

The C-17 Aircrew Training System (ATS) is a part of the C-17 Weapon System which emphasizes task/performance oriented training and will make effective use of training equipment to produce the required C-17 aircrew skills. It is based upon the 15 C-17 missions defined in the air vehicle specifications and is sized by the student throughput rate and aircraft basing. It will consist of the following types of training: initial qualification, mission qualification, continuation training (proficiency and mission), and upgrade training. The basing of the C-17 ATS will include one school squadron, five operational wings located at separate Military Airlift Command bases and the training base, two Air Force Reserve bases, and two Air National Guard bases.

Acquisition of the C-17 was divided into two phases. Phase I involves the initial training system design. In this phase three contractors were selected to work on their training system design. Phase II consists of training system design completion, full scale development, production activation, and operation and support. One contractor was selected to complete Phase II.

C-17 Maintenance Training Device (MTD) (9)

The C-17 MTD program is a part of the C-17 weapon system that will emphasize task oriented training and effective training devices to produce the required C-17 maintenance personnel skills. The goal is to deliver the MTDs identified by Air Training Command (ATC) to each of five main operating bases to be available 120 days prior to the delivery of the first aircraft at each base. The MTDs will be considered the prime source of follow-on training in lieu of the aircraft to minimize the impact of training requirements on operational aircraft. The maintenance training courseware will be developed by ATC.

The development phase of this program requires the design development, assembly, test, and delivery of twelve distinct maintenance training devices. It also includes training of the initial cadre of Air Force instructors personnel, delivery of data, and the implementation of a Maintenance Training Device Support Center.

C-20A/B Source Selection (C-SAM) (11)

The Special Airlift Mission (SAM) provides worldwide transportation for the President and Vice President of the Unites States, cabinet members, and other high ranking dignitaries of the United States and foreign governments. The C-140Bs currently fulfilling this mission are used for CONUS and European travel requirements. The C-20A/B is being used in a similar manner with occasional trips flown worldwide where the number of passengers does not warrant t. . use of a larger aircraft. The C-20A/B will carry from 14-18 passengers and a crew of 5 and is an existing "off-the-shelf" FAA certified business jet.

There is n Full Scale Development effort involved in this buy. The buy schedule of this aircraft was accelerated by two years, resulting in considerable savings to the Air Force. The overall risk of the C-SAM program is considered to be low. Primarily, because the aircraft is a commercial off-the-shelf business jet with some peculiar government communications equipment that the contractor has previously installed in the aircraft for other customers. The dollar amount of the engineering change orders was $0.3 million or .12% of the most probable cost estimate.

C-130 Aircrew Training System (ATS) (12)

The C-130 ATS provides initial and mission qualification and continuation training for all crew positions on the C-130E and C-130H aircraft. The program requires the contractor to design, develop, produce and operate the ATS with a guaranteed student being the end product.

Government furnished equipment plays a very large role in this program. The Air Force currently owns 12 C-130 simulators that will be turned over to the contractor for his use. Additionally, all the spares and support equipment unique to the C-130 simulators and some common support equipment and spares will be turned over.

The contractor will develop curriculum for the entire spectrum of training, from initial qualification to continuation training, for all crew positions. Twenty-five courses will be developed and delivered. The training system support center is the heart of the ATS. It accomplishes configuration control of all the simulators and other ATS components, maintains documentation, and modifies simulator software.

Combat Talon II (13)

The Combat Talon II System is a new production C-130H integrated with sophisticated off-the-shelf avionics systems. These avionics enable the Combat Talon II aircraft to airland or airdrop heavy payloads after flying long range at low altitude using a high precision autonomous navigation system. Mission profiles include adverse night and combat environments. Being a C-130 derivative, the aircraft can land on and take off from short unprepared fields. It is also capable of in-flight refueling as a receiver.

The procurement approach was to award separate contracts for the production aircraft and specialized Combat Talon II structural subsystems and another contractor for the avionics integration.

Cruise Missile Mission Control Aircraft (14)

The Cruise Missile Mission Control Aircraft (CMMCA) program is a Class II modification of two Air Force C-18, Boeing 707-323CF, aircraft currently owned by the 4950th Test Wing. Upon completion of the modification, both aircraft will have the capability to receive, record, and retransmit telemetry data. Each CMMCA will provide real time telemetry data processing and display, and a fully redundant Remote Command and Control System similar to the CMMCA Phase Zero aircraft. Finally, a government furnished radar will provide the means to track the position of the cruise missile while surveying the surrounding airspace for in-flight collision avoidance. Total system integration will provide instantaneous information to on-board test personnel for making critical in-flight mission and safety decisions on a real-time basis. The resulting modified C-18 will serve as the sole support aircraft for the duration of a cruise missile test from pre-launch to missile recovery; thereby, eliminating the need for fighter chase aircraft or AWACS aircraft support.

Prior to CMMCA modification the aircraft will undergo a cockpit upgrade from a commercial configuration to a militarized configuration. This effort is included in the CMMCA modification.

F-111 Digital Flight Control System (DFCS) Program (15)

The DFCS is a Class IVA modification to correct an existing safety deficiency and to improve reliability, maintainability, and commonality by replacing the current analog flight control system with a state-of-the-art, fail operational/fail safe digital flight control system for four of the six Model Design Series of the F-111. The program originated as a result of recommendations made to HQ USAF by the F-111 System Safety Group and a Blue Ribbon Panel.

The DFCS modification consists of Group B and Group A changes to the existing F/FB/EF-111 flight control system and associated modifications to training equipment and support equipment.

Technical risk is considered low, since the technology being employed throughout the Digital Flight Control System is mature and well known. The risk in this program is primarily associated with the software integration of the DFCS. There are $23.868 million in ECOs in the EMD effort and $55.551 million in the Production effort. The Development, Test and Evaluation/Initial Operability Test and Evaluation slipped one month, from September 1990 to October 1990 and the completion of Low Initial Rate of Production slipped three months from October 1991 to January 1992.

Low Altitude Navigation and Targeting Infrared Night (LANTIRN)

The LANTIRN system provides the Tactical Air Forces with the capability of conducting counter air and interdiction at night and under-the-weather using F-15E and F-16C/D Block 40/42 aircraft. The prime system consists of a navigation pod and a targeting pod used in conjunction with the aircraft's Head-Up Display and Head-Down Display.

The estimate covers all costs for EMD of both the navigation and targeting Pods. The development estimate initially contained 700 pod pairs, or 1400 pods. The quantity has since been reduced to 1067 pods; 561 navigation pods and 506 targeting pods. This decrease includes deleting the A-10 aircraft effort and a decrease in the President's FY90 Budget (17:3).

According to an Independent Technical Review conducted on the LANTIRN program, the LANTIRN program was considered to be extremely complex (16:54). The technical review gives the target recognizer credit for the bulk of the risk and complexity inherent in the LANTIRN program (16:54). The target recognizer uses immature technology which is likely to require extensive redesign before it is suitable to perform the LANTIRN mission (16:54). In addition to the high complexity of the target recognizer, "the boresight correlator, the environmental control units, power supplies, and the pods' weight and electrical power consumption provide significant technical challenges to the designers" (16:54).

The development estimate for the LANTIRN program originally had a Development Test and Evaluation (DT&E)/ Initial Operability Test and Evaluation (IOT&E) date of September 1984. This DT&E/IOT&E date slipped seventeen months to March 1986, primarily due to the time needed to test the Navigation Pods (17:4). The production decision for the Targeting Pod slipped fifteen months; however, the schedule for the Navigation Pod was on time (17:4). For the purpose of this research the overall production program will be considered to have slipped fifteen months, despite the on-time delivery of the navigation pods. The engineering change orders associated with the production program is $38.4 million in then year dollars.

Low Altitude Navigation and Targeting, Infrared, Night (LANTIRN) Simulator (18)

The LANTIRN Simulator will provide a simulation of the LANTIRN Navigation and Targeting Pods. It will be integrated with an F-16 Operational Flight Trainer to enable pilots to train in the LANTIRN mission. The LANTIRN Simulator will consist of a commercially available computational system and an image generation system. The computational system will process dynamic forward looking infrared radar image simulation with adequate detail and reality to support low level navigation and target identification.

SRAM II (19)

The Short Range Attack Missile (SRAM) II vehicle is a rocket powered missile optimized for an Air-to-Surface nuclear role. The fundamental requirement is to develop and deploy a state-of-the-art SRAM II as a replacement for the aging SRAM A. SRAM II will improve the penetrating bombers' total effectiveness and employment flexibility, and will challenge the defensive threat with a highly survivable weapon system.

The initial production quantity of 1633 units was reduced by 933 to 700 units.

The SRAM II program is considered to have high technical risk. The dollar amount of the ECOs also support this claim. There are $97.2 million in ECOs linked to the development effort and $58.2 million in the production effort. The percentage of ECOs to MPC is 9% in the development phase and 4.4% in the production phase. There is a two year slip in the EMD schedule which has also resulted in a two year slip in the production schedule. The revised production schedule is to begin in FY93.

Appendix B: C-17 Quantity Adjustment

The recurring cost profile from the December 1990 SAR was used to develop a cost improvement curve of the current estimate. The recurring base year dollars and the buy schedule taken from the SAR were input in into ICPRO to generate the cost improvement curve for the current quantity buy. The current buy schedule indicates that there will be a break in production fiscal year 1991. However, due to the production schedule slip, the one year break will not have the effect of a true break (38). For this reason, the cost improvement curve was calculated assuming no break in the production schedule and combining the advance buy in fiscal year 1991 with the fiscal year 1992 production buy. The results of the ICPRO run yielded a slope of 80.81% and a theoretical unit one (T_1) cost of $314.499 million. This slope and T_1, were input into ICPRO using the buy schedule for 182 units. The output from this run was the recurring costs by fiscal year.

To derive the adjusted funding summary, the recurring cost and non recurring costs of the current estimate were subtracted from the total cost to obtain the dollar amount of peculiar support equipment, data, and other items essential to the program (heretofore referred to simply as PSE, since PSE makes up the bulk of this figure). PSE as a percentage of the recurring cost was derived by dividing the difference obtained above by the recurring costs. The adjusted total cost was derived by adding the non-recurring costs, the recurring costs obtained from the ICPPRO run, and the percentage of PSE to recurring costs. The total cost, represented in base year 1981 dollars was converted to then year dollars using the December 1989 inflation rates in Appendix C. The C-17 adjusted estimate is contained in Table 17.

Table 17

C-17 Funding Summary
Adjusted for Quantity

Fiscal Year	QTY	Flyaway Cost BY81$		Total BY81$	Total Then Year$
		Nonrec	Recur		
1988	2	47.4	570.5	637.5	995.3
1989	6	10.8	1145.7	1399.2	1169.5
1990	10	12.5	1431.9	1973.6	3367.[illegible]
1991	0		0	0	0
1992	20	52.0	2274.2	2917.2	5160.6
1993	24	68.1	2278.4	2692.2	4926.7
1994	25		2097.7	2483.2	4690.7
1995	25		1918.7	2202.4	4290.2
1995	25		1790.9	2084.6	4185.9
1996	25		1693.0	1944.3	4026.6
1997	20		1297.1	1433.6	3060.7
Total	182	190.8	16498.0	19519.2	36973.7

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*              I C L O T               *
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*   U N I T   C U R V E   T H E O R Y  *
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TABLE I

USER INPUTS

LOT #	FIRST UNIT	LAST UNIT	AVERAGE LOT COST
1	1.00	2.00	202.10
2	3.00	6.00	135.38
3	7.00	10.00	148.68
4	11.00	16.00	184.20
5	17.00	28.00	145.00
6	29.00	40.00	138.52
7	41.00	58.00	92.88
8	59.00	76.00	80.27
9	77.00	94.00	78.44
10	95.00	112.00	74.32
11	113.00	120.00	61.19

TABLE II

LEAST SQUARES ANALYSIS

COMPUTED VALUE OF FIRST UNIT -- A	=	315.499
REGRESSION SLOPE COEFFICIENT -- B	=	-0.307
REGRESSION SLOPE PERCENTAGE -- S	=	80.821
COEFFICIENT OF CORRELATION -- R	=	-0.878
COEFFICIENT OF DETERMINATION -- R-SQ	=	0.771

TABLE III

REGRESSION LINE COMPARISON

COMPUTED LOT MIDPOINT	CALCULATED Y AT X	ACTUAL Y	PERCENTAGE DIFFERENCE
1.388	285.245	202.100	-29.149
4.311	201.398	135.375	-32.782
8.403	164.065	148.675	-9.380
13.357	142.292	184.200	29.452
22.148	121.819	145.000	19.029
34.273	106.528	138.525	30.036
49.142	95.364	92.878	-2.607
67.238	86.608	80.267	-7.321
85.294	80.505	78.440	-2.565
103.330	75.898	74.322	-2.076
116.471	73.157	61.188	-16.362

Appendix C: December 1989 OSD Inflation Rates

' WEIGHTED ** AIRCRAFT PROCUREMENT (3010) OSD RATES DECEMBER 1989

FISCAL YEAR	BASE YEAR 1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
1978	1.158	1.066	0.971	0.868	0.792	0.727	0.673	0.651	0.633	0.616	0.598	0.574	0.552
1979	1.277	1.175	1.071	0.957	0.873	0.801	0.742	0.717	0.698	0.679	0.659	0.632	0.608
1980	1.430	1.315	1.199	1.071	0.976	0.897	0.830	0.803	0.781	0.761	0.738	0.708	0.681
1981	1.557	1.433	1.306	1.167	1.065	0.977	0.905	0.875	0.851	0.829	0.804	0.771	0.742
1982	1.639	1.508	1.375	1.228	1.121	1.028	0.952	0.921	0.896	0.872	0.846	0.812	0.781
1983	1.737	1.598	1.457	1.302	1.188	1.090	1.009	0.976	0.949	0.924	0.897	0.860	0.827
1984	1.812	1.667	1.519	1.358	1.239	1.136	1.053	1.018	0.990	0.964	0.935	0.897	0.863
1985	1.870	1.720	1.568	1.401	1.279	1.173	1.086	1.050	1.022	0.995	0.965	0.926	0.891
1986	1.923	1.769	1.615	[illegible]	1.315	1.206	1.117	1.080	1.051	1.023	0.992	0.952	0.916
1987	2.005	1.844	1.681	1.502	1.371	1.258	1.164	1.126	1.095	1.067	1.035	0.993	0.955
1988	2.084	1.917	1.748	1.562	1.435	1.307	1.211	1.171	1.139	1.109	1.076	1.032	0.993
1989	2.165	1.992	1.816	1.622	1.480	1.358	1.258	1.216	1.183	1.152	1.117	1.072	1.031
1990	2.277	2.095	1.909	1.706	1.557	1.428	1.323	1.279	1.244	1.212	1.175	1.128	1.084
1991	2.361	2.172	1.980	1.769	1.614	1.481	1.371	1.326	1.290	1.256	1.219	1.169	1.124
1992	2.442	2.247	2.048	1.830	1.670	1.532	1.419	1.372	1.335	1.299	1.260	1.210	1.163
1993	2.521	2.319	2.114	1.889	1.724	1.581	1.464	1.416	1.377	1.341	1.301	1.246	1.200
1994	2.599	2.391	2.180	1.948	1.777	1.631	1.510	1.460	1.420	1.383	1.341	1.287	1.238
1995	2.680	2.465	2.247	2.008	1.832	1.681	1.557	1.505	1.464	1.426	1.383	1.327	1.276
1996	2.763	2.542	2.317	2.071	1.889	1.733	1.605	1.552	1.510	1.479	1.426	1.368	1.316
1997	2.849	2.621	2.389	2.135	1.948	1.787	1.655	1.600	1.557	1.516	1.470	1.411	1.357
1998	2.937	2.702	2.463	2.201	2.008	1.842	1.706	1.650	1.605	1.563	1.516	1.455	1.399
1999	3.028	2.786	2.539	2.269	2.070	1.899	1.759	1.701	1.655	1.611	1.563	1.500	1.442
2000	3.122	2.872	2.618	2.340	2.135	1.958	1.813	1.754	1.706	1.661	1.611	1.546	1.487
2001	3.219	2.962	2.699	2.412	2.201	2.019	1.870	1.808	1.759	1.713	1.661	1.594	1.533
2002	3.318	3.053	2.783	2.487	2.269	2.082	1.927	1.864	1.813	1.766	1.713	1.644	1.580
2003	3.421	3.147	2.869	2.564	2.339	2.146	1.987	1.922	1.870	1.820	1.766	1.694	1.629
2004	3.527	3.245	2.958	2.643	2.412	2.213	2.049	1.981	1.927	1.877	1.820	1.747	1.680
2005	3.637	3.346	3.050	2.725	2.487	2.281	2.112	2.043	1.987	1.935	1.877	1.801	1.732

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Vita

Captain Pamela J. Singleton was born on 22 December 1959 In Chicago, Illinois. She graduated from Beaufort High School in Beaufort, South Carolina in 1978 and attended the University of South Carolina in Columbia, South Carolina, graduating with a Bachelor of Science in Mathematics in 1982. Upon graduation she received a commission in the USAF through the Reserve Officer Training Corps and served her first tour at Hanscom Air Force Base, Massachusetts beginning in February 1983. During her tour at Hanscom she served as a cost analyst on the US AWACS, Saudi AWACS and NATO AWACS programs. In September 1986, she was transferred to Seymour Johnson Air Force Base, North Carolina where she was the Accounting and Finance Officer for the 4th Tactical Fighter Wing and the 68th Air Refueling Wing. She served as the Accounting and Finance Officer until her entry into the School of Systems and Logistics, Air Force Institute of Technology, in May of 1990.

Permanent Address: Star Route 5, Box 252

Beaufort, South Carolina 29902

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13. ABSTRACT (Maximum 200 words)
In today's environment of reduced funding it is imperative that an effective method of assessing likely cost growth be available early in the acquisition life cycle, and especially during the source selection process. This research sought to identify a method for predicting the range of cost growth around the most probable cost estimate generated during the source selection process. With the assistance of the Research and Cost Division of Aeronautical Systems Division, three factors were identified to be major contributors to cost growth for ASD programs; technical risk, configuration stability, and schedule risk. The data base consisted of 16 programs from ASD from 1980 to 1988. The results of this research provides a method for quickly assessing the range of potential cost growth of the most probable cost estimate; however, due to the small data base, more research must be conducted to increase the method's usefulness. Although more research is necessary, based on the data base used, configuration stability appears to be a more significant driver of cost growth in the development phase; whereas, schedule risk appears to be more significant in the production phase.

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   a. Highly Significant   b. Significant   c. Slightly Significant   d. Of No Significance

5. Comments

________________ ________________
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